Lumbo-pelvic neuromuscular control for the prevention of recurrent hamstring injuries in sprinting

By

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Declaration of work

I confirm that all this work is my own except where indicated, and that I have: Clearly referenced/listed all sources as appropriate. Referenced and put in inverted commas all quoted text (from books, web, etc) Given the sources of all pictures, data except my own.

Dedication

To my wife Cara-Ann for her support, encouragement and for covering for me at work and at home to allow me the time to complete my MSc.

Acknowledgement

I am grateful to Professor Liezel Ennion whom I have had the pleasure to work with during my MSc. I appreciate her expertise and her guidance.

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PEACE and LOVE: protection, elevation, avoid anti-inflammatories, compression, education, load, optimism, vascularisation and exercise

UAE: United Arab Emirates

PATS: Progressive agility and trunk stability

RICE: Rest, ice, compression and elevation

BMREC: Biomedical Research Ethics Committee

POPIA: Protection of Personal Information act

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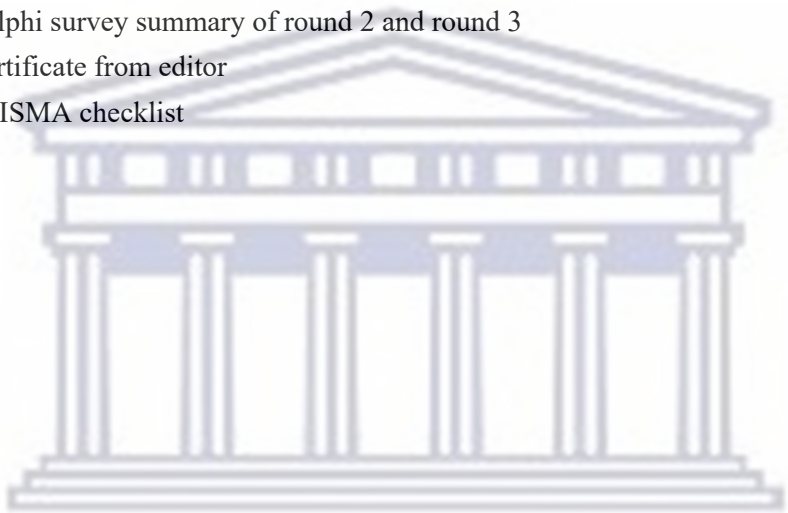


ABSTRACT:

Introduction: Hamstring injuries are the most prevalent injuries that occur in sport that require sprinting and acceleration (Small et al., 2009). A bigger concern is the high rate of recurrent hamstring strains (Comfort, 2009). The concern is that conventional hamstring rehabilitation may be inadequate, to reduce the prevalence of a recurrent hamstring injury. This study will explore if lumbo-pelvic neuromuscular rehabilitation is currently included in the rehabilitation programmes aimed at the prevention of recurring hamstring injuries in athletes involved in sprinting sports, and secondly, if consensus can be reached amongst experts on the inclusion of lumbo-pelvic control in the prevention of recurrent hamstring injuries. **Methods:** The study was conducted in two phases. In the first phase a Scoping review was used to determine if lumbo-pelvic neuromuscular rehabilitation was used in the rehabilitation of hamstring injuries to prevent recurrent injury in sports that involve sprinting, and which types of exercises are commonly used. The second phase consisted of a Delphi study, which was conducted in three rounds of online surveys. Experts were asked if they thought lumbo-pelvic neuromuscular control was important in the rehabilitation of hamstring strains to prevent recurrent injuries, as well their views on specific lumbo-pelvic neuromuscular exercises. **Results:** In the scoping review five studies were selected that were used in the review. Significant findings in these studies were that when lumbo-pelvic neuromuscular rehabilitation was used the period to return to play was shortened and after a hamstring injury there was a change of muscle activation in muscles that control the trunk and pelvis. In the Delphi study all participants agreed that lumbo-pelvic neuromuscular control rehabilitation had to be included in the rehabilitation of hamstring injuries to prevent recurrent injuries in sprinting. They also reached consensus on 12 specific lumbo-pelvic neuromuscular control exercises and when the appropriate stage of healing each

exercise should be used. **Discussion:** When comparing the significant findings in the scoping review to the studies in the literature review, there were similarities in their views of including lumbo-pelvic neuromuscular control tasks in the rehabilitation of hamstring strains. Field purposeful movement and progressive loading is a crucial component in achieving good neuromuscular control, and in turn it lowers the chances of recurrent hamstring strains. In the Delphi study the experts agreed that lumbo-pelvic neuromuscular rehabilitation should be included in the rehabilitation of hamstring injuries to prevent recurrent injury in sprinting. The experts also reached consensus on important lumbo-pelvic neuromuscular exercises and the appropriate time to use them according to the stage of healing of the hamstring strain. **Ethics:** Informed consent was obtained electronically from all participants through Google forms prior to any data being collected. Participation in the study was voluntary and participants in the Delphi study's identities were kept confidential, and only disclosed to the researchers. Participants' identity was not disclosed in any of the findings. Furthermore, codes were assigned to each participant to ensure the protection of their identity.

CHAPTER ONE: INTRODUCTION

Hamstring injuries are the most prevalent musculoskeletal injuries that occur in sports that involve sprinting and acceleration (Small et al., 2009). Sprinting is the primary cause of 57% of all hamstring strains (Small et al., 2009) As many as 54.4% will re-injure it within the first two weeks of returning to sports participation (Comfort, 2009). The re-occurrence of this injury is even more troublesome as 12% - 31% of athletes with hamstring injuries, will re-injure their hamstrings within the first year.

The high recurrence rate of hamstring strains may indicate that physiotherapists do not meet all the rehabilitation criteria required for the injured athlete. Physiotherapy rehabilitation for injured athletes are focused on trunk stability, muscle conditioning, soft tissue extensibility, proprioception, functional exercises, sport specific skills and the correction of abnormal biomechanics (Habibur Rahman, 2017) These may be achieved by including PEACE and LOVE (protection, elevation, avoid anti-inflammatories, compression, education, load, optimism, vascularisation and exercise (Dubois & Esculier., 2020). The use of electrotherapy to control oedema, massage to align soft tissue and joint and nerve manual therapy may also be used (Ramos, Arliani, Astur, Pochini, Ejnisman & Cohen, 2017). Progressive agility and trunk stabilisation has also shown to decrease selected sports injuries, especially hamstring strains (Subbiah, 2019).

A study by Sherry & Best (2004) reported that the incidence of re-injury was significantly higher in those that performed a hamstring stretching and strengthening programme compared to those that performed a progressive agility and trunk stabilisation programme. A trunk stabilisation programme is generally aimed at improving lumbo-pelvic control. The term lumbo-pelvic

control or stability is defined as “the ability to control position and motion of the trunk over the pelvis to allow optimum production, transfer and control force and motion to the terminal segment in integrated athletic activities’’ (Shield & Bourne, 2018). This is relevant as it is thought that the ability to control the lumbo-pelvic region during high-speed skilled movement may prevent hamstring injury (Sherry & Best, 2004), but this is not commonly included in hamstring rehabilitation protocols. Neglecting the inclusion of neuromuscular control training as part of hamstring injury rehabilitation may result in poor lumbo-pelvic control and a higher incidence of hamstring strain recurrence.

Poor lumbo-pelvic control is the inability to control the trunk over the pelvis (Shield & Bourne, 2018). Schuerman & Witvrouw (2017b) showed that poor lumbo-pelvic neuromuscular control predisposes the hamstring muscle to injury due to the attachment site of the biceps femoris on the ischial tuberosity of the pelvis. The lack of lumbo-pelvic neuromuscular control, during the sprinting gait, due to reduced motor control and poor muscle recruitment may result in an increased anterior pelvic tilt, creating greater eccentric loading through the hamstring (Schuermans, Van Tiggelen, et al., 2017).

The high number of the recurrence of hamstring strains after undergoing rehabilitation, shows that the rehabilitation of hamstring injuries still poses a challenge to clinicians (Comfort et al., 2009). Different approaches in literature have been discussed in the rehabilitation of hamstring strains, but there is still a lack of consensus in the literature on the best rehabilitation approach to prevent recurrence of hamstring injury (Shield & Bourne, 2018). A “gold” standard approach for the rehabilitation of hamstrings is yet to be agreed on. An explanation for the lack of consensus on the inclusion of lumbo-pelvic neuromuscular control as part of hamstring injury rehabilitation

could be the lack of research evidence supporting the objective changes that lumbo-pelvic neuromuscular control has on the hamstring (Shield & Bourne, 2018). The lack of objective evidence could be because measuring stability generally relies on subjective judgement, thereby making it difficult to quantify and or standardise.

1.8 Problem statement

Hamstring injuries are the most prevalent during sport involving sprinting and acceleration (Small et al., 2009). There is a high recurrence of this injury once athletes have been cleared to return to sports (Comfort et al., 2009). Clinically the researcher has found that a large percentage of athletes do not include neuromuscular control tasks in their rehabilitation and then re-injure their hamstring muscles when they return to sprinting. The traditional management of these injuries include conventional strengthening, stretching, electrotherapy and myofascial release, but rarely include lumbo-pelvic neuromuscular control tasks. There is some evidence in the literature supporting the inclusion of lumbo-pelvic control tasks, and clinically the researcher has seen good outcomes when incorporating lumbo-pelvic neuromuscular control tasks in athletes involved in sprinting sports that have sustained a hamstring injury.

However, minimal research has been conducted on the neuromuscular control of the lumbo-pelvic region with regard to the rehabilitation of hamstring strains. The concept of lumbo-pelvic neuromuscular control in the rehabilitation of hamstrings has not been fully explored in the available research, making reaching a clear consensus in literature on this topic difficult. Therefore, this study will explore if lumbo-pelvic neuromuscular rehabilitation is currently included in the rehabilitation programmes aimed at the prevention of recurring hamstring injuries

in athletes involved in sprinting sports, and secondly if consensus can be reached amongst experts on the inclusion of lumbo-pelvic control in the prevention of recurrent hamstring injuries.

1.2 Research questions

1. Is lumbo-pelvic neuromuscular rehabilitation currently being included as part of rehabilitation in the prevention of recurring hamstring injuries in athletes involved in sprinting sports?
2. Can consensus be reached by experts on the importance and specific exercises that should be included as part of the lumbo-pelvic neuromuscular training for the rehabilitation and prevention of recurring hamstring injuries in athletes involved in sprinting sports?

1.3 Aim of the study

This study aims to explore whether or not lumbo-pelvic neuromuscular control is currently being included as part of rehabilitation protocols aimed at the prevention of recurring hamstring injury amongst sprinting athletes, and whether consensus can be reached by experts on the importance and specific exercises thereof.

1.4 Objectives of the study

1. To explore if lumbo-pelvic neuromuscular rehabilitation is currently being included in the rehabilitation and the prevention of recurring hamstring injuries in athletes involved in sports that include sprinting.
2. To determine if a consensus can be reached amongst experts on whether lumbo-pelvic neuromuscular rehabilitation should be included in the rehabilitation and in the

prevention of recurring hamstring injuries in athletes involved in sprinting sports, and which specific exercises should be included.

1.5 Significance of the study

This study aims to determine the relevance of including lumbo-pelvic neuromuscular control rehabilitation to prevent the recurrence of hamstring injuries in sprinting athletes. This may assist in decreasing the high rate of recurrent hamstring injuries after athletes return to sports. It may also change how physiotherapists approach the rehabilitation of hamstring injuries.

1.6 Overview of the chapters

Chapter 1: introduction

Recurrent hamstring injuries are very common when sprinting athletes return to sports, and conventional rehabilitation of hamstrings are proving not to be effective. This research explores if lumbo-pelvic neuromuscular control is the missing link. This chapter discusses the primary cause for hamstring injuries and their prevalence as well as the recurrence as injuries. We identify the problem statement and research questions for it.

Chapter 2: Literature review

In this chapter, the researcher aims to display that studies highlight the importance of lumbo-pelvic neuromuscular control. The health belief model is used in this study's theoretical framework. The literature review explores what happens to the hamstring when it is strained, the role of the physiotherapist in the management of a hamstring injury and lumbo-pelvic neuromuscular protocols.

Chapter 3: Methodology

This chapter discusses how the data will be collected. A scoping review was conducted to determine if lumbo-pelvic neuromuscular rehabilitation is currently being included as part of the rehabilitation in the prevention of recurring hamstring injuries in athletes involved in sprinting sports. Then a Delphi study is used to determine if consensus can be reached by experts on the importance of the lumbo-pelvic neuromuscular training for the rehabilitation and prevention of recurring hamstring injuries in athletes involved in sprinting sports.

Chapter 4: Results

In this chapter the results of the scoping review are discussed with the use of a narrative table. All three rounds of the Delphi study are documented in graphs and tables that display the demographic of the experts as well as their views of lumbo-pelvic neuromuscular control exercises in the rehabilitation of hamstrings to prevent recurrent injury. It also explores which lumbo-pelvic neuromuscular control exercises they use in the rehabilitation of hamstrings.

Chapter 5: Discussion

The findings of the scoping review as well as how it relates to the literature review are considered. The results of the 3 rounds of the Delphi study are also discussed.

Chapter 6: Conclusion

In this chapter the summary of findings is presented. It also discusses the limitations of the study, the clinical implications, future research recommendations and concludes the study.

1.7 Operational definitions

Lumbo-pelvic neuromuscular control: The ability to control the lumbar segments and the superficial multifidus to orientate the spine on the pelvis.

Sprinting: The athlete tries to run at their maximum speed throughout the entire distance.

Expert: In the context of this Delphi study an expert is a person that has practised and is practising physiotherapy and is currently working with elite or professional athletes involved in sprinting.

Neuromuscular control: The unconscious trained response of a muscle to a signal regarding the dynamic stability of a joint

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction:

Hamstring injuries is one of the biggest reasons for time missed from sport (Small et al., 2009). The high prevalence of hamstring injuries and recurrent Hasmstring injuries can be shown in at study by Coetzee (2020), when she showed 41 acute hamstring injuries in a population of 33 participants comprising of South African male and female field hockey athletes.

The function of the Hamstring muscles is important for performance in most sports-related activities, especially when running fast (Green et al., 2020).

Acute hamstring strains often result in significant recovery time and have a lengthy period of increased susceptibility for recurrent injury (Erickson & Sherry, 2017). Recurrent injuries need significantly more time to heal compared to the original strain (Erickson & Sherry, 2017). In this chapter the theoretical framework for the study as well as the relevant literature pertaining to hamstring injury and the recurrence of injury will be presented.

2.2 Theoretical Framework

The health belief model (Anuar, Shah, Gafor, Mahmood, & Ghazi, 2020) is one of the most widely used models for understanding health behaviour. The model's crucial factors are an individual's perceived seriousness, perceived severity, perceived benefits, perceived barriers to action and the exposure to factors that prompt action and confidence in the ability to succeed (Anuar et al., 2020).

The health belief model can also be used to assist with the design of short-term or long-term interventions (Anuar et al., 2020).

There are five essential components that need to be addressed in the design of these interventions. In this study the **first three vital** components were used to explore and guide the

initial development of guidelines on how to implement lumbo-pelvic neuromuscular rehabilitation in the prevention of recurrent hamstring injuries the best (Anuar et al., 2020).

1. **Gathering information by conducting a health needs assessment and other efforts to determine who is at risk and the population that should be targeted.**

When deciding on the reason for conducting this study, the researcher identified that many athletes participating in sprinting sports reinjured their hamstring when returning to sports after an initial hamstring injury. Sprinting was identified as the leading cause of hamstring injuries, so the population that hamstring injuries were prevalent in was any sport that involved the athlete to accelerate and sprint. A recurrent hamstring injury results in the athlete being away from returning to play for an extended period. The way these athletes were rehabilitated for the initial hamstring injury was then reviewed and assessed to see if there were certain criteria that were not being met. When subjectively assessing these athletes, many of them reported that the main focus in their rehabilitation for the hamstring injury was focused on reducing pain, restoring hamstring strength and length. It was identified that Lumbo-pelvic neuromuscular rehabilitation was not routinely included in the rehabilitation of these athletes. In this study the first phase was to conduct a scoping review of the literature. This was to explore whether or not lumbo-pelvic neuromuscular control was included in the rehabilitation of hamstring strains in sprinting athletes to prevent recurrent injuries.

2. **Conveying the consequences of the health issues associated with risk behaviour in a clear and unambiguous fashion to understand perceived severity.**

In the second phase of the study, experts in sports rehabilitation were recruited to participate in a Delphi study to reach consensus on the exercises that should be included for the prevention of recurrent hamstring injuries. The consequences of recurrent hamstring injury were clearly described in the information sheet, even though participants were experts in rehabilitation and would be aware of these consequences. The consequences of recurrent hamstring injury are a longer period away from sport as well as a higher financial burden on the athlete or the team. Hamstring strains (Grade 2) can take up to 21 days to heal sufficiently for the athlete to return to play. The probability of reinjuring a hamstring muscle also increases every time the hamstring is strained.

3. Communicating to the target population the steps that are involved in taking the recommended action and highlighting the benefits of the action.

From the scoping review and in the Delphi study that was conducted, it was clear that including lumbo-pelvic neuromuscular control in the rehabilitation of hamstrings in sprinting athletes is important and it can reduce the risk of hamstring re-injury. In turn this can reduce the period away from their sport. Based on this step, guidelines and recommendations on how to best incorporate lumbo-pelvic neuromuscular rehabilitation according to the stages of healing were developed, which can be shared with rehabilitation professionals and athletes.

4. Providing assistance in identifying and reducing barriers to action.

This study did not identify or aim to address the barriers to action pertaining to incorporating lumbo-pelvic neuromuscular rehabilitation as part of recurrent hamstring injury prevention. This can be explored in a subsequent study.

5. Demonstrating actions through skill development activities and providing support that enhances self -efficacy and the likelihood of successful behaviour changes.

When completing the Delphi study, we may be able to conclude that it is important to include lumbo-pelvic neuromuscular control rehabilitation in hamstring rehabilitation to prevent recurrent injuries in sprinting athletes. We may also be able to assist not only the athlete but also therapists with the best form of lumbo-pelvic neuromuscular control rehabilitation in hamstring rehabilitation. Not only does the athlete do conventional hamstring exercises and stretches, but evidence-based rehabilitation that has been proved to reduce recurrent hamstring injuries.

Only focusing on reducing the pain on movement and palpation of the hamstring, restoring the strength and length of the hamstring, may allow the athlete to return to sprinting sports sooner. However, a large percentage of these athletes sustain recurrent hamstring injuries.

Neuromuscular control rehabilitation of the lumbo-pelvic region is often neglected or not included in the rehabilitation of hamstrings, even though literature has shown its importance. It provides safer functioning of the hamstring and reduces the excessive anterior tilt, which reduces the already large levels of strain produced by eccentric force of the hamstring during the terminal swing phase. Sports specific rehabilitation is also mentioned in the clinical setting, in the context of running, accelerating and sprinting. This would basically be getting the athlete to run, accelerate and sprint. Schuermans et al. (2017a), showed that the biomechanics or gait of sprinting is affected by the pelvis and trunk of athletes who have suffered hamstring strains. This shows that if the athlete's biomechanics or gait of sprinting needs to be corrected the muscles that control the trunk and pelvis need to be addressed. Schuermans et al. (2017a) also stated that proximal neuromuscular control, known in layman's terms as "core stability" is considered to be of key importance in preventing primary and secondary hamstring injuries. This information

combined with the intervention that was developed in this study can be used to inform skill development activities such as workshops for athletes and rehabilitation professionals in future.

2.3 Classification and pathophysiology of hamstring injury

The Hamstring is made up of three muscles, they are the Bicep Femoris, Semimembranosus and the Semitendinosus. The function of the Hamstring is to produce hip extension, knee flexion, but also acts as a stabiliser to the pelvis and knee (Brukner & Khan, 2010). A hamstring strain usually occurs when its muscle fibres are involved in a combination of high muscle-tendon unit forces (active or passive), extensive muscle-tendon unit lengthening beyond moderate lengths, and high-velocity movements (Hickey, Opar, Weiss & Heiderscheit, 2022).

Neuromuscular coordination, and particularly lumbo-pelvic function is vitally important in safe hamstring function (Schuermans, Van Tiggelen, Danneels & Witvrouw., 2017). It has been shown that the lumbo-pelvic system has a direct influence on the hamstrings and vice versa (Reis & Macedo, 2015). This is because of the attachment points of the hamstring to the pelvis. If there is an increased pelvic tilt and or the hip joint is not optimally positioned, this puts increased tension on the proximal hamstring before a sprint is performed. If the physiotherapist understands the pretension position, where the pelvis is anteriorly tilted due to poor lumbo-pelvic neuromuscular control, which then causes greater eccentric forces through the hamstring. The combination of the anterior tilt of the pelvis, hip extension and knee extension increases the chances of sustaining a hamstring strain.

Mueller-Wohlfahrt et al., (2013; pg. 2) describes the "traditional" muscle injury grading according to clinical and imaging investigations as:

> "**Grade 1** (mild) Strains affect only a limited number of fibres in the muscle. There is no decrease in strength and there is a fully active and passive range of motion. Pain and tenderness are often delayed to the next day.
>
> **Grade 2** (moderate) Strains have nearly half of muscle fibres torn. Acute and significant pain is accompanied by swelling and minor decrease in strength.
>
> **Grade 3** (severe) Strains represent the complete rupture of the muscle. This means either the tendon is separated from the muscle belly or the muscle belly is torn into two parts. Severe swelling and pain and complete loss of function are characteristics of this type of strain."

2.4 Prevalence of acute hamstring and recurrent hamstring injuries

Hamstring injuries is the most prevalent injury in sprinting sport (Small et al., 2009), and results in large period of absents from sport (Erickson & Sherry, 2017). Clinically the researcher has noticed this over the years, however after searching (Ebsco-host, Pubmed and Pedro), no literature on the prevalence of hamstring injuries in low to middle income countries or Africa were published, or could be identified in the past ten years. Hamstring injuries represent 39% of all reported sports injuries and may result in prolonged time loss due to injury, ranging from 17 to 90 days (Silvers-Granelli, Cohen, Espregueira-Mendes & Mandelbaum, 2021). Recurrence of a hamstring injury is 12%-63%, with one-third of these injuries occurring in the first year after the initial injury (Silvers-Granelli et al., 2021). Most hamstring injuries have been reported to

occur during high intensity sprinting actions (Kalema, Schache, Williams, Heiderscheit, Trajano & Shield, 2022).

2.5 Functional role of the Hamstrings in athletic performance in speed development

Ground reaction force plays a major role in the being able to accelerate and reach maximal speed (Morin et al., 2015). Three major factors have been considered in speed development, firstly the hip extensors such as the Hamstring has been shown to be a play and important role in production of ground reaction force as athletes reach maximal speeds (Morin et al., 2015). Secondly, the hamstring acts as a breaking force to reduce the kinetic energy of the lower limb during the late swing phase to increase stride frequency, and lastly lower force production of the hamstrings produces slower speeds while sprinting (Morin et al., 2015).

2.6 The role of the physiotherapist in the management of hamstring injuries.

Physiotherapists are first line practitioners and usually have first contact with the injured athlete as they have the necessary skills to assess and treat acute hamstring injuries. When an athlete sustains an acute hamstring injury, a form of the R.I.C.E (Rest, Ice, Compress, Elevate) protocol is often started (Ramos et al., 2017). The physiotherapist will be responsible for a thorough assessment of the injury to establish the grade of the hamstring strain when the pain inhibition has settled. The physiotherapist is primarily responsible for the acute management of the hamstring injury by controlling swelling and bruising, reducing pain, and restoring range of movement and strength (Habibur Rahman, 2017). The physiotherapist is also responsible for the management and rehabilitation in the final stages of the rehabilitation, such as return to running

and sports specific tasks and finally conducting return to sports testing to determine if an athlete has met the criteria to return to sports (Habibur Rahman, 2017).

The physiotherapist will generally perform the clinical assessments for hamstring injuries to clear the athlete to return to sports. It usually consists of testing for pain, ROM and strength. It does not represent complete muscle recovery and readiness for return to sports (Erickson & Sherry, 2017), Erickson & Sherry (2017) statement of this may be due to the fact that neuromuscular readiness may not have been achieved, even though the soft tissue of the hamstring may have been restored. The significant areas to evaluate athletes for information for the risk of recurrent hamstring injuries are sports performance, match play, hamstring strength and running (Green et al., 2020).

Clinically it is not evident that physiotherapists routinely include lumbo-pelvic neuromuscular control focused exercises in the rehabilitation of hamstring injuries. It is for this reason that the missing link in clinical practice could be the inclusion of lumbo-pelvic neuromuscular control tasks, in the rehabilitation of these athletes.

2.7 Lumbo-pelvic neuromuscular control protocols

Consensus has not been reached on the best rehabilitation protocol to prevent recurring hamstring injuries (Van Dyk, et al., 2016). This is evident due to the high recurrence rate in athletes after returning to sports (Comfort et al., 2009). Athletes that sustain a hamstring injury have more than twice as high a risk of sustaining a new hamstring injury (Erickson & Sherry, 2017). A high recurrence rate is suggestive of an inadequate rehabilitation programme and premature return to sports, or a combination of both (Erickson & Sherry, 2017). In clinical practice there is the perception that lumbo-pelvic control is an important part of injury prevention and performance enhancement (Perrott, Pizzari, Opar & Cook., 2012). Although there is minimal

evidence to show that poor lumbo-pelvic neuromuscular control is an important and a modifiable risk factor for hamstring injuries, it is still believed to be efficient and effective in the prevention of recurring hamstring injuries clinically (Shield & Bourne, 2018). The difficulty is to demonstrate the effectiveness of neuromuscular training as most studies fail to do so (Zemková & Hamar, 2018). The difficulty in demonstrating the effectiveness of neuromuscular training is due to protocols utilised in laboratories that only partially fulfil the current needs for testing under sports-specific conditions (Zemková & Hamar, 2018). Muscles like the gluteus medius are essential for lumbo-pelvic stability. However, the specific training of muscles such as the gluteus medius has not been included in protocols described to date (Guerrero-Tapia, Martin-Baeza & Cuesta-Barriuso., 2021).

Neuromuscular control is the unconscious trained response of a muscle to a signal regarding the dynamic stability of a joint (Ageberg et al., 2010). Neuromuscular performance can be regarded as the ability of the neuromuscular systems to functionally control and drive movement by appropriate use and coordination of muscular strength and endurance, muscle recruitment patterns, proprioceptive feedback and reflex activity (Faude et al., 2017). Simply, these are muscles that respond subconsciously to allow efficient and effective movement. Therefore, in the rehabilitation process of the hamstring one can not only focus on conventional strength training and fascicle lengthening of the hamstring, but also has to work on exercises that target quality of movement and emphasises joint control in all biomechanical planes (Ageberg et al., 2010). Optimal function of the lumbo-pelvic complex relies on coordinating active, passive and neuromotor systems in order to form and force closure mechanisms to stabilise the region (Macdonald, 2017). Not having optimal function of this region means that there will be impaired capacity of the pelvic ring to transfer load between the trunk and legs (Macdonald, 2017).

Restoring the mechanical restraints is not sufficient for functional recovery, as this would neglect the neuromuscular controlling mechanism required in sports specific activities (Clausen et al., 2017).

Neuromuscular training has been integrated into clinical practice to improve sensorimotor control and achieve compensatory functional stability (Ageberg et al., 2010). Neuromuscular deficits can increase the risk of injury, as it affects balance, stability, leg power and leg strength (Faude et al., 2017). Exercises such as climbing up and down stairs, squats and landing from a jump, should be added to the hamstring rehabilitation process, as it enhances bilateral symmetry and motor control of the leg (Kaya et al., 2019). Poor performance in testing of single leg balance and the star excursion balance test for fast bowlers in cricket, at the start of the season showed that there was a heightened risk of injury (Olivier et al., 2016). Improvement in lumbo-pelvic control may be responsible for reducing these risk factors (Olivier et al., 2016).

2.8 Sprinting and hamstring injury

Considering that sprinting is the primary mechanism for hamstring injuries (Small, 2009), having good lumbo-pelvic neuromuscular control would be considered important during sprinting. Neuromuscular multimodal injury prevention programmes showed large effects in neuromuscular performance during sprinting performance and sports specific tests (Faude et al., 2017).

The study by Schuermans et.al (2017a) showed that it was mostly in the airborne phases of sprinting that there is an increased anterior pelvic tilt. As 80% of sprinting takes place in the airborne phase, there is an increased period of elongation stress placed on the hamstring. This is due to the fact that the ischial tuberosity of the pelvis is an attachment site of the biceps femoris.

Due to the proximal attachment of the biceps femoris, the lumbo-pelvic kinematics may influence strain put on the hamstring. In the study by Schuermans et.al (2017a) it was reported that participants with previous hamstring injuries had an increase in thoracic lateral flexion and that their thoraco-lumbo-pelvic kinematics were less stable.

There is very little evidence from a small number of randomised trial studies, in the approaches for managing hamstring injuries, and even less with clinical follow-ups (Mason et al., 2007).

When making this statement I was addressing actual randomised trial studies in management of hamstring injuries and not systematic or meta-analysis on this topic (examiner 2)

Sherry & Best (2004) reported that athletes that performed the progressive agility and trunk stabilisation programme (PATS), showed a significantly lower re-injury rate at both two weeks and 12 months, following full return to sporting activity compared to the conventional stretching and strengthening control group. Sherry & Best (2004) suggested that the reduced recurrence rate was possibly due to the enhanced neuromuscular control of the lumbo-pelvic complex. Common criticism of hamstring programmes that only emphasise eccentric strength training and display a lack of attention to adjacent muscles to the hamstring. Previously strained hamstrings have been found to have neuromuscular inhibition which will reduce activation, especially in the eccentric phases as shown in a study by (Fyfe, et al 2013).

Emami, Arab & Ghamkhar (2014) also showed that unusual stresses were placed on the lumbo-pelvic region, after an athlete had strained their hamstring resulting in synergistic muscles substituting and becoming overactive. It is therefore imperative to re-establishing lumbo-pelvic neuromuscular control after hamstring injury rather than focusing solely on the injured hamstring muscle during rehabilitation.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

This chapter will describe the research approach and study design utilised for meeting the study's objectives. Data was collected in two phases and the methods used to collect data for each phase will be described separately. The study setting, population, sampling strategy, procedure for data collection and analysis of study findings will be presented. Finally, the ethics considerations applied in this study will be elaborated on.

3.2 Overarching research approach and study design:

This study utilised a multiple method approach, and was conducted in two stages. In the first stage a scoping review of the literature was conducted, followed by a Delphi study.

3.3 PHASE 1: SCOPING REVIEW

A scoping review is a tool to determine the coverage of a body of literature on a given topic and give clear indication of the volume of literature and studies available as an overview of its focus (Munn, Peters, Stern, Tufanaru, McArthur & Aromataris. 2018). The Scoping review was used in this study to see if lumbo-pelvic neuromuscular control rehabilitation was used in the rehabilitation of hamstring injuries and the effects of it on recurrent hamstring injuries. It was also to determine how widely it is used and if it was a common form of criteria that was used in returning athletes to their sports. The scoping review was conducted in accordance with the five stages of conducting a scoping review. Arksey & O'Malley's five stages of conducting a scoping review: Stage 1 was to identify the research question that would be used to search for literature. Stage 2 was to identify relevant studies found in literature. Stage 3 was used to select the studies

that would be used in the review. Stage 4: Charting the data. Stage 5: Collating, summarising and reporting the results (Arksey & O'Malley, 2005).

Stage 1: Identification of the research question

After exploring the literature and based on the researcher's clinical experience it was noted that the inclusion of lumbo-pelvic neuromuscular rehabilitation is often neglected during the rehabilitation of a hamstring injury.

The research questions that guided the scoping review were; 1) "Is lumbo-pelvic neuromuscular rehabilitation currently being included as part of the rehabilitation in the prevention of recurring hamstring injuries in athletes involved in sprinting sports?". 2) If so, which lumbo-pelvic neuromuscular exercises are currently being used in the prevention of recurrent hamstring injuries?"

Stage 2: Identification of relevant studies

Only English, full-text articles, published between 2010 - 2021 were included in the search. The following databases were used: Ebsco-host, Pubmed, Pedro, CINAHL and Science direct. The following search terms/words were used in different combinations: hamstrings, sprinting, prevention and neuromuscular. Any other reviews were excluded from the study. The following keywords were used in the search: "Lumbo-pelvic neuromuscular control", "hamstring strain rehabilitation" and "hamstring injury prevention. The search combinations that were used were: "hamstring injuries prevention". "Neuromuscular control rehabilitation in hamstrings" "hamstring injury prevention" "lumbo-pelvic neuromuscular rehabilitation in hamstrings"

Stage 3: Study selection

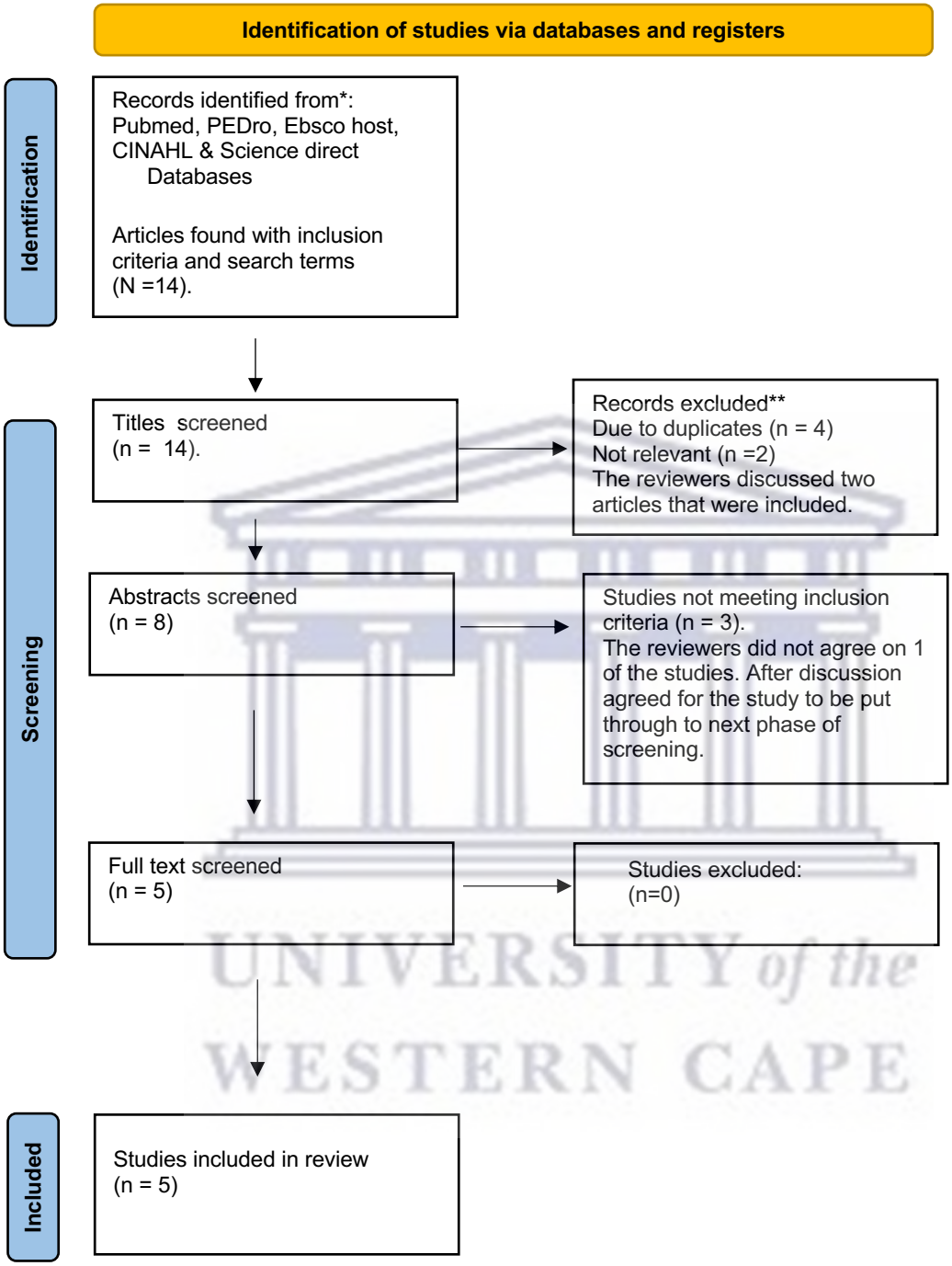
Relevant study titles were recorded and documented on the PRISMA diagram. There were four duplicates found in different databases that were removed. Scoring of the titles was done independently by two reviewers, to avoid bias. When scoring the titles, the relevance was rated as: 0: having no relevance; 1: some relevance and 2: very relevant. If a 0 was scored by both reviewers, the study would be excluded. If one reviewer did not include the study, but the other did, they would discuss it and then decide whether to include or exclude study. A total of 14 studies were identified across all databases, four of these hits were duplicates. There were 10 study titles that were screened, the first step of screening was to screen the titles of the study on its relevance to this study. The relevance of the titles was determined by the population of sprinting athletes, mentioning neuromuscular control rehabilitation and hamstring injuries. Out of 10, eight studies were retrieved to screen the abstract. The reviewers disagreed on two studies but concluded that they should be selected to make it through to the abstract screening process.

In the next screening phase only the abstracts of the eight studies were read. They were scored out of 3 again by both reviewers. Out of the 8, 5 studies were selected for the next phase of screening. The reviewers disagreed on one of the studies, but after a discussion decided that the study made it through to the final round of screening. In the final stage of screening the full text of all 5 studies were read.

After reading the full text of the final 5 studies both reviewers agreed that all 5 studies will be included in the scoping review. Although two of the studies' main outcomes did not directly touch on the importance of lumbo-pelvic neuromuscular control in the rehabilitation of

hamstring injuries to prevent recurrent injuries, sections of the discussion did indicate that it does play an important role in hamstring injury prevention.

PRISMA 2020 flow diagram for new systematic reviews which included searches of databases and registers only



*Consider, if feasible to do so, reporting the number of records identified from each database or register searched (rather than the total number across all databases/registers).**If automation tools were used, indicate how many records were excluded by a human and how many were excluded by automation tool

Stage 4: Charting the data

A table was used for data extraction (figure 1) that included the general information of the study and specific information. This table was formulated using Microsoft Excel. Information relating to the population, outcomes measures, study design, main findings & conclusion.

Figure1: Narrative table

Study number	Authors, Year	Title	Aim of study	Study design	Participants/Population	Outcome measures	Results

Stage 5: Collating, summarising and reporting results

All studies that met the inclusion criteria were included. Studies were collated and summarised narratively and reported when lumbo-pelvic neuromuscular training was included in the rehabilitation in the prevention of recurring hamstring injuries in athletes that are involved in sprinting sports. Using this information, questions were developed to be used in the first round of the Delphi survey.

3.4 PHASE 2: DELPHI STUDY

3.4.1 Delphi study methodology:

3.4.1.1 Study Design

The Delphi survey is a group facilitation technique, which is an iterative multistage process, designed to transform opinion into group consensus (Hasson, 2000). This Delphi survey consisted of three rounds and was used to determine if consensus can be reached by experts on whether lumbo-pelvic neuromuscular rehabilitation should be included in the rehabilitation in the prevention of recurring hamstring injuries in athletes involved in sprinting sports or not.

3.4.1.2 Setting, study population, sampling strategy and size

Experts were approached using LinkedIn, contacting the physiotherapists' private practice where they worked and contacting the medical offices of professional teams. Participants were considered experts if they are (1) currently practising as a registered physiotherapist; (2) work within the domain of sports and orthopaedics and (3) treat and rehabilitate athletes that are involved in any sports that requires sprinting. (4) The years of experience was at least 5 years working with athletes involved in sprinting sports.

A total of 26 experts were approached using social media such as LinkedIn, Instagram or via their private practice contact forms, where they were and sent the information sheet detailing the details of the Delphi study. There is no consensus in literature for the ideal sample size, but a minimum of 10 participants in medical research is accepted (Akins et al., 2005). A total of 12 participants agreed to participate in the study. The 12 participants provided their personal email addresses to which the surveys would be sent. Seven of the participants that consented to participate resided in the Western Cape, two in Pretoria, one was from Canada, one from Germany and one from the United Arab Emirates. All participants were working with elite and professional athletes involved in sprinting sports.

3.4.1.3 Instrument and procedure of Data collection

The Delphi survey was conducted on Google forms which was emailed to the participants who consented to participate. The participants completed surveys anonymously and were not aware of who else was participating in the survey. Participants received a consent form, a self-developed basic demographic survey, which included questions such as, "years of experience in the field", "qualification" and "types and level of athletes they work with?". All three rounds of the Delphi

study were also conducted through Google forms. The Delphi surveys can be found in the appendix.

The first round of the Delphi study asked participants whether they felt that the inclusion of lumbo-pelvic neuromuscular control was important in the rehabilitation of hamstring injuries to prevent recurrent hamstring injuries or not and introduced the rehabilitation exercises identified in the scoping review. Participants were also asked to add any additional lumbo-pelvic neuromuscular exercises for the rehabilitation to prevent recurrent hamstring injuries.

In total it took all participants a month to complete the first round of the Delphi survey. Participants were given 4 weeks to complete one round of the study, a reminder to complete a round of the survey was sent out after two weeks. In total it took 3 months to complete data collections for the Delphi study. Consensus was reached on an answer if 70% of the participants agreed on a certain point (Barrett & Heale, 2020).

The results of the first round were then summarised and sent to the participants.

In the second round of the Delphi survey, exercises collected from the Scoping review that consensus was not reached on, were revisited and participants were asked to rate their importance once more. The additional rehabilitation exercises provided by the participants were collated and then used to ask participants to rate the importance of these exercises. The results of the second round were summarised and then sent to the participants.

In the third-round exercises that consensus was reached on was put in a table that best represented the stage (stage of healing) that these exercises should be conducted in as part of the rehabilitation protocol. Participants were then asked to agree or disagree on if they thought the

exercises were conducted at the correct stage. If they disagreed, they were asked what their reason for disagreeing was.

3.4.1.4 Data analysis

The data from all three rounds of the Delphi study was collected via Google forms. Descriptive analysis reported as frequencies and means were used to describe the characteristics of the study sample. Consensus was reached if nine or more out of 12 participants agreed or disagreed on the questions.

3.4.1.5 Scientific rigour

The validity of the study ensured by carefully planning the study, selection of the participants, data collection and analysis of this data. The validity and reliability of the study would be hard to achieve with this study alone. It would require a similar study to be performed, with a different set of experts. The results of that study would then have to be compared to this study to see if similar results are achieved. Testing the validity and reliability of this study is also hard as no study that could be found in literature had the same or similar research question. To prevent bias the researchers practised reflexivity through the data analysis process, understanding that the way the researcher clinically practised and thought may alter how he interprets the results. The Google forms analysis to questions also assisted with eliminating some bias by giving a more objective view in terms of how questions were scored. The generalisability of the results in this study was possibly not too applicable to a different population, as this study specifically needed participants that are experienced and skilled in the rehabilitation of elite or professional sprinting athletes.

3.4.1.6 Ethics statement:

Ethics clearance to conduct this study was obtained from the Biomedical Research Ethics Committee (BMREC reference number: BM21/10/51). Informed consent was obtained electronically from all participants through Google forms prior to any data being collected. Participation in the study was voluntary and participants in the Delphi study's identities were kept confidential, and only disclosed to the researchers. Participants' identity was not disclosed in any of the findings, and codes were assigned to each participant to further protect their identity. Participants were free to withdraw from the Delphi study at any time without any negative consequences. Information gathered during the study was strictly confidential, only the researcher and researcher's supervisor had access to the information. Electronic data was kept on the researcher's personal computer, in a password protected folder. Participants in the Delphi study were informed of the final results after the study was concluded. Personal information collected adhered to the Protection of Personal Information Act 4 of 2013 (POPIA). This was to protect the participant's personal information, protect them from theft and discrimination, enforce their right to privacy and to create a balance between the free flow of access to information and regulate how the information was processed. To ensure that this happened participants were required to sign a consent form to confirm that they understand the POPI Act and were only asked for information that was relevant to or necessary for the study. Participants' information will be kept for five years after which it will be permanently deleted (2019, November 5).https://popia.co.za/act/.

CHAPTER FOUR: RESULTS

4.1 Introduction

This chapter will discuss the essential findings of the final five articles that were included in the scoping review. These five articles explored if lumbo-pelvic neuromuscular rehabilitation was currently being included as part of rehabilitation protocols in the prevention of recurring hamstring injuries in athletes involved in sprinting sports. A summary of each of the five articles will be presented. The findings of the three rounds of the Delphi study to reach consensus on the inclusion of lumbo-pelvic neuromuscular control rehabilitation will then be presented.

4.2 PHASE 1: SCOPING REVIEW

Five articles were finally included in the scoping review of the literature. All five articles were published in the past seven years (2015-2021). The total population size included was 243 participants. Of the 243, 15 participants' genders were not disclosed in the study conducted by (Jiménez-Rubio et al., 2019). The remainder of the other participants were made up of one female and 227 males.

4.2.1 Predisposing risk factors for hamstring injury

In the study by Kalema et al (2022) the athletes with hamstring injuries had lower gluteal and trunk muscle activation compared to those without hamstring injuries.

Sprinting was also identified as the leading cause of hamstring injuries and that the act of sprinting after a hamstring injury, exposed neuromuscular faults in biomechanics and movement patterns (Kalema, Duhig, Williams, Donaldson & Shield, 2022; Scheurmans, Danneels, Van Tiggelen, Palmans & Witvrouw, 2017a). In the study by Kalema et.al (2022) it was said that the biggest risk factor for hamstring injuries was exposure to maximal sprinting effort.

4.2.2 Benefits of inclusion of neuromuscular control exercises

The studies explored the effects of hamstring injuries on sprinting performance and gait, time to return to sports and risk factors leading to hamstring injuries. In all five studies, neuromuscular control exercises were included and identified as an important component of the rehabilitation process in the rehabilitation of hamstring injuries. It also showed that rehabilitation that included neuromuscular control exercises resulted in less time between day of injury and the return to play (Jiménez-Rubio et al., 2019). The studies by Askling et al., (2013) and Mendiguchia et al., (2015), supported this fact as the benefits of the inclusion of neuromuscular rehabilitation was demonstrated with shorter periods away from sports participation.

Table 4.1:Narrative table:

Study number	Authors, Year	Title	Aim of study	Study design	Participants/Population	Outcome measures	Results
1	J. Scheurmans, L. Danneels, D. Van Tiggelen T. Palmans, & E. Witvrouw 2017a	Proximal Neuromuscular Control Protects Against Hamstring Injuries in Male Soccer Players: A Prospective Study With Electromyography Time-Series Analysis During Maximal Sprinting.	The aim of the study was to identify if there was a difference in the neuromuscular activation of the muscles that control the pelvis and the trunk during sprinting.	Case control study.	60 Male Soccer players.	Surface electromyogtraphy (sEMG) assessment during maximal acceleration and full speed sprinting.	Players who did not experience a hamstring injury during follow-up had significantly higher amounts of gluteal muscle activity during the front swing phase. The players that did not have a hamstring injury, had higher trunk muscle activity during the backswing phase. The risk of these players sustaining a hamstring injury during follow-up lowered by 20% and 6% with a 10% increment in normalised muscle activity of the gluteus maximus during front swing and the trunk muscles during backswing respectively.

2	S. Jimenez-Rubio, A.Navanda, J. Rivilla-Garcia & V. Paredes-Hernandez 2019	Validity of an On-Field Readaptation Programme Following a Hamstring Injury in Professional Soccer.	To develop and validate a new, functional, on field programme for the rehabilitation and readaptation of soccer players after a hamstring strain injury through consultation with a panel of experts. To determine the usefulness of the program through its application in professional soccer players.	A prospective, longitudinal rehabilitation and readaptation programme.	15 Strength and conditioning and rehabilitation fitness coaches with professional experience in football with elite clubs and national teams in Europe. 19 male professional soccer players.	13 exercises were designed and were validated by experts and then applied to 19 male soccer players.	The programme selected by the experts proved to be effective in its practical application in the study, in returning athletes to play. Experts rated 13 items highly. The soccer players had 24 days to successfully complete all 13 drills to be cleared to return to play. The return to play protocol was aimed at re-educating on-field purposeful movement and progressive loading that would be conducted on the field of play. The lack of this may result in weakness and poor neuromuscular control resulting in adaptive changes in biomechanics and motor patterns of sporting movements. The return to play was 22.42 days.

3	R. Kalema, S. Duhig, M. Williams, A. Donaldson & A, Shield 2022	Sprinting technique and hamstring strain injuries: A concept mapping study.	To explore expert opinion to identify the components of sprinting technique they believed to be risk factors for hamstring strain injuries.	Delphi Study	Twenty-three experts, majority male (1 female) Participants are professionals or semi-professionals with 5 or more years' experience in a sports organisation as a physiotherapist, strength and conditioning coach, sport physician, sprint coach or academic/ researcher with relevant qualifications.	Participants were asked to brainstorm ideas based on their experience and on their knowledge of sprinting technique and the research evidence about reducing risk of sprint - related hamstring injury as well as what the components of sprinting technique were that they believed are contributing to the risk of hamstring injuries. Mixed - method research design	Neuromuscular and tendon properties were the second highest risk factors for hamstring injuries out of the five clusters decided on by the experts panel. The other four clusters were: Training prescription, kinematics parameter/technical skills, kinetic parameters, and hip mechanics. Maximal sprinting exposure is the biggest risk factor for hamstring injuries (training prescription).
4	C. Askling, M. Tengvar & A. Thorstensson 2013	Acute hamstring injuries in Swedish elite football: a prospective randomised controlled clinical trial comparing	To compare the effectiveness of two rehabilitation protocols for acute hamstring	Prospective randomised comparison of two rehabilitation protocols.	75 male and female football players. 6 females 69 males	The main outcome for this study was the time to return to full participation in football team training and	Time to return was shorter in L-protocol (mean 28 days) than in C- protocol (51 days) . Stretching-type protocol took significantly longer to return than sprinting

		two rehabilitation protocols	injuries with varying emphasis on muscle-tendon lengths by evaluating time needed to return to full participation in football.			availability for match selection.	Both protocols included trunk and pelvis stabilisation exercises however L-protocol aimed at loading hamstring during eccentric phases where C-protocol was based on more conventional exercise with less emphasis on length. L-protocol mean 43 vs 23 days C-protocol 74 vs 41 days L- type protocol. The L - protocol was significantly more effective than the C-protocol in both injury types and one reinjury registered in C - protocol.
5	J. Mendiguchia, E. Martinez-Ruiz. J Morin, P. Samozino, P. Edouard, P. Alcatraz, F. Esparza-Ros & A. Mendez-Villanueva	Effects of hamstring-emphasized neuromuscular training on strength and sprinting mechanics in football players.	To examine the effects of a neuromuscular training programme combining eccentric hamstring muscle strength, plyometrics, free/resisted	Randomised control study	51 Male soccer players	Outcomes were to measure sprinting performance and knee extension and flexion isokinetic strength.	The addition of two weekly sessions of neuromuscular training induced substantial improvements in eccentric and concentric hamstring strength. This improved peak torque ratio of hamstring to quadricep, which reduced the likelihood of sustaining a hamstring strain.

	2015		sprinting exercises on knee extensor and flexor muscles strength, sprinting performance and horizontal mechanical properties of sprint running in football players.				Players that may have sustained a hamstring strain were not reported on.

4.2.3 Summary of narrative table findings:

Schuermans, Danneels, et al., (2017a) researched muscle activation in association with hamstring injury. They found that players that presented with a hamstring injury, had reduced activity of gluteal muscles and trunk muscles during the swing phases of gait or sprinting. The reduced activity of gluteal and trunk muscles impacted on the biomechanics and movement patterns of athletes during sprinting. The reduced activity of gluteal and trunk muscles would increase the risk of sustaining a hamstring injury.

The study by Kalema et.al (2022) considered the risk factors for hamstring injury from experts' perspectives. Experts considered the neuromuscular and tendon properties as the second highest risk factors for hamstring injuries out of the five clusters decided on by the expert panel. These five clusters were: Training prescription, neuromuscular and tendon properties, kinematics parameter/technical skills, kinetic parameters and hip mechanics. This study showed the importance of neuromuscular control properties the experts place on the rehabilitation of hamstrings as it was rated second highest.

It also stated that maximal sprinting exposure is the biggest risk factor for hamstring injuries. Excessive anterior tilt of the pelvis and improper eccentric control of swing phase during sprinting increased the risk of hamstring injuries. All these components show that lumbo-pelvic neuromuscular control is an imperative part in the rehabilitation of hamstrings to prevent recurrent hamstring injuries.

The most important finding in the study by Askling (2013) was that soccer players with hamstring injuries were given different rehabilitation protocols. The L-protocol hamstring injury rehabilitation showed that there was a shorter period of days away from training and returning to play. There was a mean of 28 days compared to the C-protocol mean of 51 days. It also showed fewer recurrent injuries during the rehabilitation process. The C-protocol consisted mostly of a stretching type protocol while the L-protocol was aimed at loading the hamstring especially during the eccentric phase. Both protocols included a pelvic and trunk stabilisation exercise but when paired with the eccentric lengthening protocol (of the L-protocol), it proved to be superior. This is significant as it shows that when pairing eccentric lengthening protocol with pelvic and trunk stabilisation the yield shorter time away from sport.

The study by Mendiguchia, et al. (2015) showed that the addition of 2 weekly sessions of neuromuscular training to the participants normal football training, sprint, and strength training, induced substantial improvement in eccentric and concentric hamstring strength. This reduced the likelihood of sustaining a hamstring strain. This is an important finding as football training alone showed that eccentric muscle strength was unchanged, and that sprinting performance induced a small negative change and horizontal mechanical properties were unchanged. This would result in a higher risk of hamstring injury.

4.3 PHASE 2: DELPHI STUDY

Demographic details of participants: A total of twelve experts participated in the study. Out of the 12 participants, eight were males and four were females. Out of the 12 participants nine were in the 30-39 age category and three participants in the 40-59 age category. Five participants (42%) have their masters in physiotherapy. On average the participants have been working as a qualified Physiotherapist for 13.17 (Range: 9 - 21; SD +- 5.13) years.

When considering the proportion of time experts spent with sprinting athletes, four participants spent 21% - 40% of their total time working with sprinting athletes, 41%-60% for three participants; 61%-80% for two participants and 81%-100% for three participants. (figure 4.1).

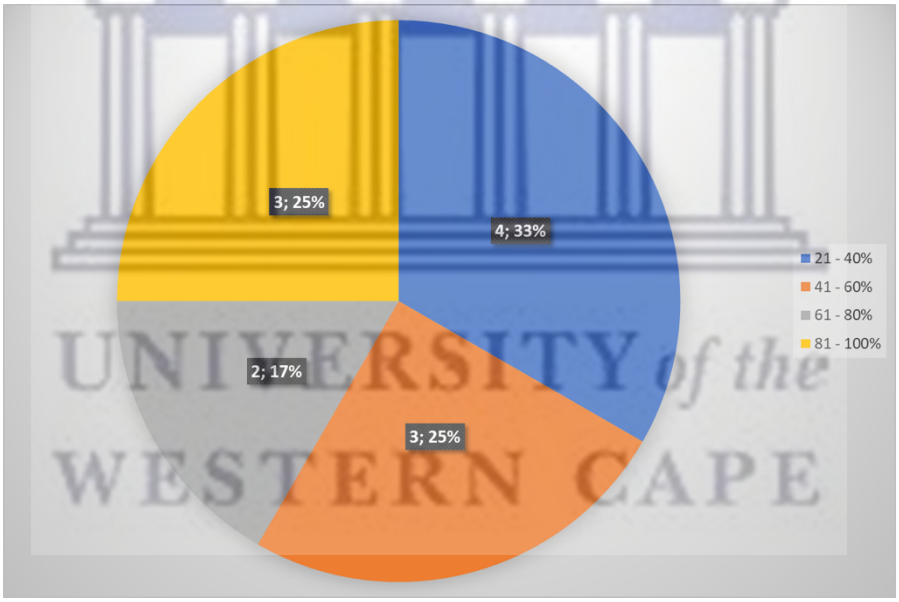


Figure 4.1: Proportion of time spent with sprinting athletes.

All participants work with Elite and professional level athletes. Participants worked in South Africa (n = 9; 75%), the UAE (n = 1; 8.3%), Germany (n =1; 8.3%) and Canada (n = 1;8.3%).

Participants were asked to use a Likert scale to rate the importance of the inclusion of lumbo-pelvic neuromuscular control exercises in the rehabilitation of hamstrings to prevent recurrent hamstring injuries. The scale was out of five (1- Not important at all; 2 - Slightly important; 3 - Important; 4 - Fairly important and 5 - Very important). The majority of participants (n = 11; 92%) rated it as either very important (n = 6; 50%) or important (n = 5; 42%) (Figure 4.2).

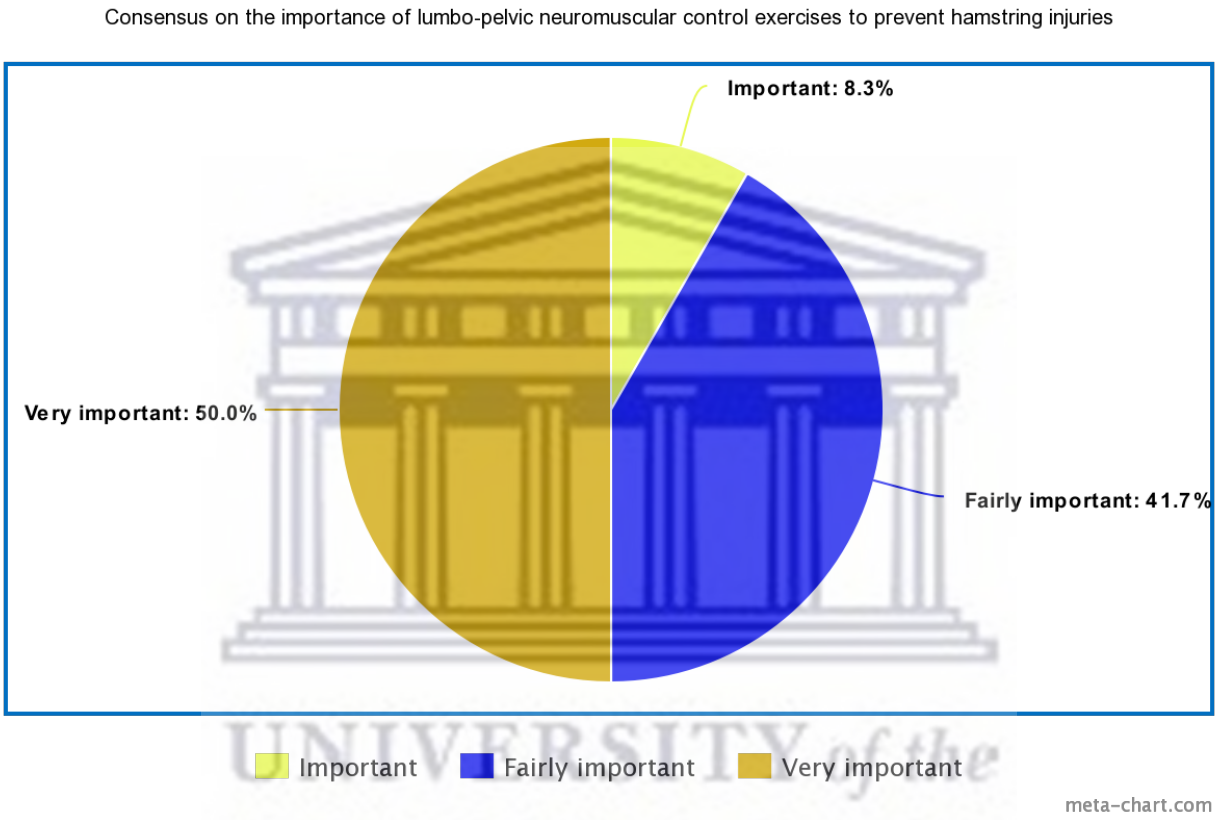


Figure 4.2 Consensus on the importance of lumbo-pelvic neuromuscular control exercises to prevent hamstring injuries.

When participants were asked if they include lumbo-pelvic neuromuscular control exercises in the rehabilitation of hamstrings to prevent recurrent hamstring injuries, 100% of participants said that they do.

In the studies of the scoping review, 13 lumbo-pelvic neuromuscular control exercises were identified. Participants were asked to rate these exercises out of five (1- Not important at all; 2 Slightly important; 3 - Important; 4 - Fairly important and 5 - Very important). Consensus was reached on 9 out of the 13 exercises. The participants rated the exercises as follows on Table 4.2 below:

Table 4.2 Lumbo-pelvic neuromuscular control exercises found in the studies of Scoping review

Exercise	Description	Rating	Consensus
Extensor (glider)	The athlete lies in supine position with one hip of targeted hamstring at 90 degrees flexion. Hip is held in position by the athlete using hands. The leg being held, the knee is moved through the full range of movement and back to starting position.	n = 6; 50% not as important, n = 6; 50% important	Consensus not reached
Discontinuous aerobic drills	Aerobic graded exercises (E.g., running shuttles) that are performed with 5 to 10 minutes of rest between increments of workload.	n= 4; 33% not as important, n= 8; 67% important	Consensus not reached
Single leg bridge with heel dig	Lie on your back, and place your hands on the floor for stability as you bend your right leg while the left leg remains straight. Digging the bent leg heel in surface the glutes are activated to clear the buttocks and straight leg of the surface.	n = 7; 58% not as important, n= 5; 42% important	Consensus not reached
Cable machine or resistance band hip extension to flexion pendulum	Cable or resistance band connected to ankle from the front the leg is then swung into hip extension and back into hip flexion. The exercises are performed with control, not allowing the resistance to dictate the speed.	n=6; 50% not as important, n= 6; 50% important	Consensus not reached
Diver	From an upright trunk position, flex forward at hip to 90 degrees while standing on the affected leg, and with affected leg	n = 2; 17% not as important, n	Consensus reached

	knee flexed by 10-20 degrees. Extend the uninjured leg backwards as far as possible and hold this position for as long as you can.	= 10; 83% important	
Glider	The athlete stands in front of a squat rack holding onto the bar with both hands. The injured leg is placed in front, resting on the heel on the ground with the knee flexed to 10-20 degrees. The back leg foot is positioned on top of a slider. The athlete is instructed to perform a backward gliding movement on the uninjured leg and stop before the injured leg experiences pain. The movement back to the starting position is done by using both pulling action by both arms.	n =3; 25% not as important, n= 9; 75% important	Consensus reached
Contract relax for hamstring hip at 90 degrees	The athlete is lying supine with injured leg hip at 90° and the knee flexed. The athlete is instructed to flex the knee into the resistance of the clinician or bench, by activating the hamstrings and holding the position for approximately 5 sec. After the hold the athlete relaxes contraction. This action is repeated approximately 10 times.	n= 10; 83% not as important, n= 2; 17% important	Consensus reached
Lateral displacement and controlled landing drills	Lateral displacement tasks are where sideward movements are performed such as shuffles or lateral step ups. Controlled landing task is where the athlete will have to land on a single leg with good balance.	n=3; 25% not as important, n=9; 75% important	Consensus reached
Single leg deadlift	Begin by standing with feet shoulder width apart with a kettlebell or dumbbell in your hand. Lean forward in your hips, your weight onto one leg while your uninjured leg starts to extend straight behind you. Your arms should be hanging straight down. Slowly bring in your extended leg and return to the starting position.	n=3; 25% not as important, n=9; 75% important	Consensus reached
Intermittent, adapted high-speed running drills	An example of this is repeated sprints with a minimal recovery period in between.	n= 2; 17% not as important, n= 10; 83% important	Consensus reached

Deceleration, direction changing tasks and pivoting	Classic examples of this are the agility T where cones are placed 5 metres apart in the shape of the letter T. the athlete then has to sprint, accelerate and decelerate while forward running, laterally shuffling and backward running to touch each cone as fast as possible. Figure 8 running is also used.	n=3; 25% not as important, n= 9; 75% important	Consensus reached
Drills involving actions similar to injury mechanism without external force	In the case of a hamstring strain a dumbbell snatch or plyometric box jump can be used to simulate the triple extension action.	n= 3; 25% not as important, n= 9; 75% important	Consensus reached
Sports specific drills	Ball skills, hand/feet eye coordination drills while moving or running.	n = 2; 17% not as important, n = 10; 83% important	Consensus reached

Participants were also asked to add any additional lumbo-pelvic neuromuscular control exercises that they felt were important to add to the 13 exercises identified in the scoping review. Eight exercises were added by the participants. The exercises are as follows:

Table 4.3: Additional lumbo-pelvic neuromuscular control exercises added by experts

Exercises	Description
Nordic hamstring exercises	Kneeling with both knees on a pad (for knee comfort) and lowering under control while the ankles are held in place by a clinician.
Single leg squat	Standing on one leg, the other leg (injured or uninjured) extended to the front, slowly lower your buttock towards the ground. Then slowly return to the starting position.
Hamstring tantrums either in a prone position with a physio ball, or supine with large loop resistance bands	The athlete lies down on their stomach and the clinician holds a Swiss ball firmly onto their lower back The athlete slowly starts to alternate their heels up to the ball as if to kick it.

	The ball will bounce the heel back off so control it and return to the starting position. Over time to progress the speed is increased .
Explosive hamstring tasks with lumbo-pelvic control	An example of these is performing a bridge on a Swiss ball and alternating legs by marching. The speed of this is slowly progressed.
Progressive agility and trunk stabilisation	A trunk stabilisation exercise is to challenge trunk muscles to increase the ability to regulate movement, to maintain proper coordination between muscles, and to create stability of the trunk against external resistance. Progressive agility is movement drills such as figure 8 running, shuttles and ladder drills. The speed in which these are done is slowly increased.
A Kicks and B Kicks	The A kick is performing a high knee kicking motion while slowly moving forward. The B kick is performed the same as the A kick, but with knee extension at the end of the sequence.
Copenhagen adduction exercise	These exercises are performed in a side plank position while adducting the hip over the lower leg.
Single leg proprioception on foam pad	Standing on a foam pad with one leg hand on hips and trying to remain balanced in an upright position.

In the second round of the Delphi survey, participants were asked to reconsider the four exercises identified in the scoping review that consensus was not reached on. These exercises were the extender, single leg pelvic bridge with heel dig, cable or resistance band extension to flexion pendulum and discontinuous aerobic drills as well as rating the additional eight exercises.

The results were as follows: (Table 4.4)

Table 4.4 Lumbo-pelvic neuromuscular control exercises that consensus was not reached on revised.

Exercises	Rating	Consensus
Extender	n = 5; 42% not as important, n = 7; 58% important	Consensus not reached
Single leg pelvic bridge with heel dig	n = 2; 17% not as important, n= 10; 83% important	Consensus reached
Cable machine or resistance band extension to flexion pendulum	n=8; 67% not as important, n= 4; 33% important	Consensus not reached
Discontinuous aerobic drills	n= 5; 42% not as important, n= 7; 58% important	Consensus not reached

The additional lumbo-pelvic neuromuscular control exercises recommended by the participants were also rated out of 5.

The results of this were as follows: (Table 4.5)

Table 4.5 Additional lumbo-pelvic neuromuscular control exercises added by experts that consensus was not reached on revised.

Exercises	Rating	Consensus
Nordic hamstring exercises	n=1; 8% Not important n=11; 92% Important	Consensus reached
Single leg squat	n=3; 25% Not important n= 9; 75% Important	Consensus reached
Hamstring tantrums either in a prone position with a physio ball, or supine with large loop resistance bands	n=4; 33% Not important n=8; 67% Important	Consensus not reached
Explosive hamstring tasks with lumbo-pelvic control	n=3; 25% Not important n=9; 75% Important	Consensus reached
Progressive agility and trunk stabilisation	n=5; 42% Not important n=7; 58% Important	Consensus not reached

A Kicks and B Kicks	n=5; 42% Not important n=7; 58% Important	Consensus not reached
Copenhagen adduction exercise	n= 7; 67% Not important n=5; 33% Important	Consensus not reached
Single leg proprioception on foam pad	n= 7; 67% Not important n=5; 33% Important	Consensus not reached

In round 1 and round 2 consensus was reached on 13 lumbo-pelvic neuromuscular control exercises for hamstring rehabilitation, of which 12 were considered important and one was not as important.

In round 3 the final 12 exercises that experts reached consensus on in round 2, as being important in the rehabilitation to prevent recurrent hamstring injuries, were organised into a table by the researcher. These exercises were ordered in accordance with the stage of healing they should be prescribed in (Table 4.6).

The exercises were also put into the table according to the rating by participants in descending order from most to least important. The participants were then asked to agree or disagree with the layout out of these exercises.

Table 4.6 Exercises in accordance to stages of healing

DESTRUCTION/ACUTE PHASE (Week 1-2)	**REPAIR PHASE (Week 2-3)**	**REMODELLING PHASE (Week>3)**
The Diver: (83% importance)	Single leg Squat (75% importance)	Nordic hamstring exercises (92% Importance)
Single leg pelvic bridge with heel dig (83% importance)	Lateral displacement and controlled landing drills (75% importance)	Intermittent adapted high-speed running drills (83% importance)
Cable machine or band extension to flexion pendulum (75% importance)	Deceleration, direction changing tasks and pivoting (75% importance)	Sport specific drills (83% importance)
The Glider (75% importance)	Drills involving actions similar to injury mechanism without external force (75% importance)	Single leg deadlifts (75% importance)

The exercises placed in the different stages of soft tissue healing was done agreed upon by the experts in the Delphi study, to create a protocol of lumbo-pelvic neuromuscular exercises that cand be done in addition to conventional rehabilitation for hamstring strains. (examiner 2)

The results of round 3 were as follows: three participants (16.7%) disagreed with the table and ten (83.3%) of participants agreed that the exercises were placed in the correct phase of tissue healing.

The reasons for two of participants disagreeing with the table were that there were no A kicks, B kicks as well as progressive agility and trunk stabilisation tasks in the repair phase. The third participant mentioned that the timing of the exercises was not appropriate for the stage of healing.

CHAPTER FIVE: DISCUSSION

The studies of Erickson & Sherry (2017) and Comfort et al. (2009) showed that there is increased susceptibility for recurrent hamstring injuries after the initial injury. They also found that there is an increased time loss for the athlete to return to play. Hamstring injuries are known to keep the athlete out of training and play for a lengthy period (Askling et.al., 2013). The study also showed that this period was significantly longer (51 days) in protocols based on conventional exercises with less emphasis on the lengthening of the hamstring (Askling et.al, 2013). However, the behaviour of both athlete and physiotherapist clinically has not altered in terms of their rehabilitation approach, especially after a recurrent injury. This has also been recorded in the study by Erickson & Sherry (2017), when they stated that recurrent hamstring injuries are due to inadequate rehabilitation and clearing the athlete to return to sport before the necessary criteria was met. This is confirmed by Jimenez-Rubio, Navanda, Rivilla-Garcia & Paredes-Hernandez (2019) when they stated that return to play protocol should be aimed at field purposeful movements and progressive loading. The lack of this results in poor neuromuscular control.

All participants in the Delphi study agreed that lumbo-pelvic neuromuscular control rehabilitation should be included in the rehabilitation of hamstring injuries to prevent recurrent injuries.

Sherry and Best (2004) showed that purely focusing on improving the flexibility and strength of the hamstring was less efficient than following a progressive agility and trunk stability (PATS) program, as the PATS program had a much lower rate of recurrent hamstring injuries. In both studies by Scheurmans (2017a) & (2017b), the author showed that after sustaining a hamstring injury, the lumbo-pelvic neuromuscular control of the injured athlete was affected. It changed the

sprinting gait of these athletes by having an increase in anterior pelvic tilt and lateral trunk flexion, which would potentially increase the load on to the hamstrings by moving the two points of the attachment further from each other (Scheurmans, 2017). This should indicate that clinically we should address the lumbo-pelvic deficit to restore the strength, length and flexibility of the hamstring in tandem. This is problematic as the biggest risk for hamstring injury is maximum sprint exposure as shown in the scoping review by Kalema, Duhig, Williams, Donaldson & Shield (2022).

Although the participants in the Delphi study agreed on its importance they disagreed or did not reach consensus on all the rehabilitation exercises found in the studies of the scoping review. There was also a big difference in how the participants in the Delphi study viewed the importance of certain exercises. Certain exercises, such as those found in the Aspetar hamstring protocol and those discussed by Sherry & Best (2004), were viewed as not as important by some participants. even though they have evidence backing them (Brukner, 2015). This might be due to the fact that participants have not come across these research articles and protocols, or that they don't feel that the theoretical research directly applies to the clinical or practical setting. This may be due to the experts not achieving good results with these techniques.

The additional exercises provided by the participants were similar to certain aspects such as Nordic hamstring tasks and hip adductor [as in Copenhagen adduction tasks (examiner 2)] exercises, but only two participants focused on the addition of trunk stability and single leg stance pelvic control tasks. This could be that these two participants included this in the rehabilitation of their athletes and achieved good or better results with the inclusion of these exercises. As there was no further survey to ask these two participants, in why they included

these exercises, the exact reason why this is the case is unknown. This is then one of the limitations of this study.

Nordic exercises in literature have shown to be highly effective in the rehabilitation of hamstring injuries and are used at the highest level of sport that involve sprinting (Cuthbert, Ripley, McMahon, Evans, Haff & Comfort, 2020). However, it has not changed the high incidence of recurrent hamstring injuries.

These aspects of lumbo-pelvic neuromuscular rehabilitation are highly recommended in literature to prevent recurrent hamstring injuries (Sherry & Best, 2004). However, it may be that participants might have assumed these exercises fell under the group of exercises in lateral displacement and controlled landing and deceleration, direction changing tasks and pivoting. If this is the case, then this may have altered how the participants in the Delphi study answered this question.

In the third round of the Delphi study, the exercises that consensus was reached on were put into the phase of tissue healing that was most appropriate in the rehabilitation process. These phases are the destruction phase, repair phase and the remodelling phase.

The exercises in the destruction phase were:

The diver and glider (Aspetar - Aspetar Hamstring Protocol, n.d.): They are both hamstring gliders that introduce load to the hamstring during triple extension. Triple extension in sprinting is when the hamstring undergoes the greatest eccentric force. These don't work on eccentric loading of the hamstring but require good lumbo-pelvic control due to the position and transitions of the rehabilitation tasks.

The single leg bridge with heel dig allows for isometric loading of the hamstring, while using the hamstring and the gluteus muscle to extend the hips forward, simultaneously controlling the pelvis to avoid it to drop (Aspetar - Aspetar Hamstring Protocol, n.d.).

The band or cable hip extension works on both the concentric and eccentric loading of the hamstring while having to maintain lumbo-pelvic control.

These four exercises are a good start for the hamstring rehabilitation process as they are able to control the amount of load placed on the hamstring and address lumbo-pelvic neuromuscular control. The ability to control the load is important so as not to overload and re-injure the healing tissue.

The exercises in the repair phase, start to progress the loads endured by the hamstring, with a greater challenge on the system to control eccentric loads and lumbo-pelvic neuromuscular control. The three rehabilitation tasks that focus on these aspects are the single leg squat, lateral displacement and controlled landing drills. and deceleration, direction changing tasks and pivoting (Jiménez-Rubio et al., 2019). The fourth rehabilitation task in this phase is drills involving actions similar to injury mechanisms without external force. In this case it would be the act of sprinting. Assuming that the hamstring and supporting components were not working optimally or overloaded, which in turn resulted in the injury, we know that these components will need to be addressed in the rehabilitation process. As mentioned, the most vulnerable period is during triple extension in the sprinting gait. So, activities during this task could be to control the triple extension motion and then increasing the speed and force of deceleration. So, this may be done by breaking down the running gait and rehabilitating different phases of the running gait. This would be done while maintaining good lumbo-pelvic control.

The exercises in the remodelling phase would start to place larger loads in terms of resistance and speed to try to replicate what the athletes' hamstrings will have to endure during their sports and more specifically sprinting and acceleration. Nordic hamstring exercises have shown to be very effective during the hamstring rehabilitation process and puts the hamstring through large eccentric and concentric loads while being able to maintain good lumbo-pelvic control (Aspetar - Aspetar Hamstring Protocol, n.d.). Single leg deadlifts place the hamstring through the same respective loads but place larger emphasis on lumbo-pelvic neuromuscular control as most of the task requires transitions with a single leg stance. Then getting the athlete to perform running and sprinting tasks is an important part of the return to play criteria. Hence, the one exercise that consensus was reached is intermittent, adapted high-speed drills (Jiménez-Rubio et al., 2019). These drills will start the athlete at a speed that they are comfortable with and then slowly increase as they improve. During this type of drilling ongoing subjective monitoring should be done between the physiotherapist and athlete to monitor if the athlete can push, maintain, or lower the intensity of the run.

Consensus was reached on the timing of these exercises for hamstring rehabilitation in the stages of tissue healing, but 3 participants felt that certain crucial rehabilitation tasks were missing from the chosen rehabilitation tasks and that the timing of the exercises was not appropriate for the stage of tissue healing. The two participants that felt that crucial rehabilitation tasks were missing from the chosen rehabilitation tasks, highlighted the results from the study by Sherry & Best 2004 as well as the omission of the A and B drill. The third participant felt that certain rehabilitation task was started to early which may cause the disruption of soft tissue healing (Crockett, 2011).

These findings have showed there is a significance in the inclusion of lumbo-pelvic neuromuscular control rehabilitation in the rehabilitation of Hamstring injuries. They show that there is lower incidence of recurrent hamstring injuries and less time away from sport (Askling et al., 2013) when of lumbo-pelvic neuromuscular control rehabilitation is included.

Nordic Hamstring curls and standing cable or band pendulums I feel are definitely lumbo-pelvic neuromuscular exercises. If the athlete is unable to control the spine over the pelvis during these exercises the exercise will not be done efficiently or have the desired outcome for load put on the Hamstring.

The studies indicated for me to review by examinator 2 were both reviewed for use in this study information in the study by

Green, B., Bourne, M. N., van Dyk, N., & Pizzari, T. (2020) was then used in this study.

CHAPTER SIX: CONCLUSION

6.1 SUMMARY OF FINDINGS

There were five articles in the final selection in the Scoping review. It showed that there was not much current evidence on the importance of lumbo-pelvic neuromuscular control rehabilitation in the rehabilitation of hamstring injuries to prevent recurrent injuries in sprinting athletes. What these articles did show is that the inclusion of the lumbo-pelvic neuromuscular control rehabilitation shortened the time it took to return athletes to play and improved the athletes' sprinting gait which in turn reduced the chance of sustaining a recurrent hamstring injury.

In the Delphi Study all participants reached consensus on the inclusion of lumbo-pelvic neuromuscular control rehabilitation in the rehabilitation of hamstring injuries. In rounds 1 and 2 consensus was reached on 13 of the lumbo-pelvic neuromuscular control exercises, 12 were regarded to be important and 1 was regarded as not important. In round 3 these 12 exercises were organised according to the stage of healing they should be prescribed in, and 83.3% of the participants agreed with the exercise placements. Seeing that the majority of the experts agreeing with the placement of these exercises in the specific stages of healing, this gives physiotherapist in future a loose framework on how to include lumbo-pelvic neuromuscular control tasks into the rehabilitation of Hamstrings. This may prove to be the missing link in the rehabilitation of Hamstring injuries.

6.2 LIMITATIONS OF STUDY

Using the Delphi study survey format in this study did not always allow for participants to explain why they felt an exercise was important or not. Having this option might have given us more information on the thought process of the participants in the rehabilitation of hamstring

injuries. Also knowing the participants' general protocol of rehabilitation of hamstring injuries may have given us more insight into their process.

6.3 RECOMMENDATIONS

Lumbo-pelvic neuromuscular rehabilitation should be included in the rehabilitation of hamstring injuries to prevent recurrent hamstring injury. To improve the rehabilitation progress accurate re-assessment is imperative to monitor actual changes in hamstring force loads and biomechanical changes to the lumbo-pelvic complex. The use of force decks to assess this may be a very valuable asset. The limitation of experts not being able to explain the reasoning for responses to questions such as exercise selection and when they are appropriate to use, showed that including the option to include focus groups or interviews to explore their reasons in future studies will be valuable.

6.4 CLINICAL RECOMMENDATIONS

As shown in the literature review, as well as the consensus reached by participants in the Delphi study on the importance of the inclusion of lumbo-pelvic neuromuscular rehabilitation in the rehabilitation in hamstring rehabilitation, this could reduce the high recurrence rate of hamstring injuries. Single leg lumbo-pelvic rehabilitation tasks such as the single leg bridge, single leg squat, lateral displacement, deceleration, direction changing tasks and pivoting as shown in the study are effective and will prepare the athlete better for the return to play. It was also shown to reduce the time an athlete is out of play and the cost rehabilitation. However, as stage 3 of the Delphi study has shown it is imperative to know the appropriate stage to use these exercises as excessive loads at the wrong time could reinjure the hamstring.

6.5 RECOMMENDATIONS FOR FUTURE RESEARCH

Applying the findings of this study to actual athletes with hamstring injuries involved in sprinting sports, by using the exercises that consensus was reached on in the allocated stages of healing. The clinical effectiveness of adding lumbo-pelvic neuromuscular rehabilitation into the rehabilitation of hamstring injuries to prevent recurrent injuries can then be assessed for its effectiveness. Taking the athlete through initial assessment and acute rehabilitation all the way to return to play, we can then also measure the time from injury to return to play. Another important component to address is how clinically effective the inclusion of the exercises that consensus was reached on are to these athletes, by measuring the effects they have on their lumbo-pelvic complex and the strain placed on their hamstring muscles. This can be measured with the use of force decks.

6.6 CONCLUSION

There is minimal evidence that lumbo-pelvic neuromuscular rehabilitation is currently clinically being included in the rehabilitation in the prevention of recurring hamstring injuries in athletes involved in sprinting sports. There is also not much evidence in the relevant literature of its use. In the Delphi study consensus was reached by the experts on the importance and specific exercises that should be included as part of the lumbo-pelvic neuromuscular training for the rehabilitation and prevention of recurring hamstring injuries in athletes involved in sprinting sports. The study also showed when the specific exercises should be performed according to the stage of healing of the hamstring muscle to prevent recurrent injury.

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Appendices

UNIVERSITY of the WESTERN CAPE

50 YEARS of hope, action & knowledge

30 September 2022

Mr W Kerspuy
Department of Physiotherapy
Faculty of Community and Health Science

BMREC Reference Number: BM21/10/51

Project Title: Lumbo-pelvic neuromuscular control for theprevention of recurrent hamstring injuries in sprinting.

Approval Period: **26 September 2022 – 25 September 2025**

I hereby certify that the Biomedical Science Research Ethics Committee of the University of the Western Cape approved the scientific methodology and ethics of the above-mentionedresearch project and the requested amendment to the project.

Any further amendments, extension or other modifications to the protocol must be submittedto the Ethics Committee for approval.

Please remember to submit a progress report annually by 30 November for theduration of the project.

For permission to conduct research using student and/or staff data or to distribute research surveys/questionnaires please apply via: https://sites.google.com/uwc.ac.za/permissionresearch/home

The permission letter must then be submitted to BMREC for record keeping purposes.

The Committee must be informed of any serious adverse event and/or termination of the study.

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DELPHI STUDY INFORMATION SHEET
FOR PARTICIPANTS

You have been invited to be a part of this study because of your expertise and experience in the field of sports physiotherapy and neuromusculoskeletal domain. Please read this information sheet before deciding to take part. It will explain why the research is being done and what taking part will involve for you.

- What is the study about?

We are carrying out this study to determine the importance of the inclusion of lumbo-pelvic neuromuscular control in rehabilitation for the prevention of recurring hamstring injuries. The study will be led by Wade Kerspuy in collaboration with the University of the Western Cape. We have reviewed the literature on this topic and consensus has not been met yet. In this study we want you to give your views and ideas on this topic.

- What is involved in taking part?

A Delphi study is a way of combining views of multiple experts to reach an agreement on a subject. Taking part will involve completing 3 rounds of online questionnaires. Questionnaires will take approximately 30 minutes to complete. Answers can be saved and completed later. Each round will last for 2 weeks. After each round you will receive a summary of the feedback of that specific round. There will be no face-to-face communication between participants and your identities will not be disclosed to other participants.

- Are there any risks?

It is very unlikely that taking part in the study will cause you any harm or emotional stress. You can stop taking part whenever you want. However, any responses up until that point will be withdrawn from the study.

- How conferential are my answers and personal information in this study?

All responses to the questionnaire will be anonymous to the other participants. All data will be stored on a password protected folder on the researcher's computer. The study was approved by University of the Western Cape's Humanities and Social Science research ethics committee. Your personal information will be protected by the Protection of Personal Information act (POPI) and all its protocol will be followed.

- What will be done with the results?

We will produce a report summarizing the study, which will be sent to you via email. Information will be used as part of the researchers MSc thesis. The information will also be used to start the conversation between physiotherapists and athletes on the importance of lumbo- pelvic neuromuscular control on hamstrings.

- Who do I contact if I want more information about this study?

We will send you an email with a link to the Delphi study consent form and the POPI consent form on Google Forms as well as the link to the Delphi questionnaire. You can take part by following the link on the email. We will send you one reminder and then if we have not heard from you we will assume that you do not wish to take part and remove you from the list of participants (for each of the 2nd and 3rd questionnaires we will also send you a reminder after one week). If you would prefer not to receive any further communications from us, please let us know via the contact details below.

Wade Kerspuy
2863404@uwc.ac.za

Thank you for taking the time to read this information sheet and for considering taking part in this study.

DELPHI STUDY CONSENT FORM

Please read this consent document carefully before you decide to participate in this study. The researcher will answer any questions before you sign.

Study Title:
Lumbo-pelvic neuromuscular control for the prevention of recurrent hamstring injuries in sprinting.

Purpose of the study:
We are carrying out this study to determine the importance of the inclusion of lumbo-pelvic neuromuscular control in rehabilitation for the prevention of recurring hamstring injuries.

Potential risks to participant:
It is very unlikely that you will be harmed or experience any emotional stress from this study.

Confidentiality:
Only the participant and the researcher will know the identity of participant in this study. None of the of the participants will interact with each other or know each other's identity. The participants name will not be mentioned in the study. The study will also act in accordance with the Protection of Personal Information act (POPI).

Voluntary participation:
At any time, the participant may withdraw from the study, however any responses up until that point will be withdrawn from the study.

Whom to contact if you have any questions:
The researcher Wade Kerspuy can be contacted
2863404@myuwc.ac.za

Agreement:
I have read the procedure described above. I voluntarily agree to participate in the procedure, and I have received a copy of the information sheet.
The privacy and security of personal information of participants are important to us. We will only process personal information, which includes collect, use, store and share such information in accordance with the POPI act and if processing is permitted by law, for legitimate interest or if the participant has provided consent.

Participant : _____

Date : _____

1. DEMOGRAPHIC INFORMATION

All information will be protected and adhere to the Protection of Personal Information act (POPI)

1.1 Sex *

Mark only one oval.

- Male
- Female
- Other:

1.2 Age

Mark only one oval.

- 21-29
- 30-39
- 40-59
- 60 or older

1.3 Qualifications

1.4 Working experience including time period (include practices and/or teams) *

1.5 Time spent in clinical practice with athletes in sprinting sport *

Mark only one oval.

- <20%
- 21-40%
- 41-60%
- 61-80%
- 81-100%

1.6 Highest level of athlete you work with *

Mark only one oval.

- Weekend warrior (only exercises once a week and play on weekend)
- School level (provincial or national level)

- ◯ Competitive amateur (Club/varsity level) Professional and Elite
- ◯ (Provincial/National)

1.8 In which country are you currently living and working?

DELPHI SURVEY: QUESTION 1

2. Scoping review findings

The studies included in the Scoping review found that there is limited evidence in the importance of lumbo-pelvic neuromuscular control in the prevention of recurrent hamstring injuries. The studies did show that sustaining a hamstring injury will alter the control of an athlete's trunk and pelvis. This influenced the athletes sprinting gait in position and firing sequences of muscles.

2.1 How important is lumbo-pelvic neuromuscular control in the rehabilitation of hamstringsto prevent recurrent injuries? Please rate your answer out of 5 (0 being no importance and being very important).

2.2 Do you include lumbo-pelvic neuromuscular control in the rehabilitation of hamstringsto prevent recurrent injuries?

- ☐ Yes
- ☐ No

2.3 When conducting the scoping review, rehabilitation exercises included were as below. Are they important for lumbo-pelvic neuromuscular control rehabilitation? Please rate each exercise out of 5 on its importance.

1 - Not important at all 2 - Slightly important 3 - Important 4 - Fairly important 5 - Very important

Mark only one oval per row.

	1	2	3	4	5
The extender (hamstring glider)	◯	◯	◯	◯	◯
The diver (hamstring glider)	◯	◯	◯	◯	◯
The glider (hamstring glider)	◯	◯	◯	◯	◯
Single leg pelvic bridge with heel dig.	◯	◯	◯	◯	◯
Contract-relax for hamstring with hip in 90° flexion	◯	◯	◯	◯	◯
Cable machine or resistance band extension to flexion pendulum	◯	◯	◯	◯	◯
Lateral displacement and controlled landing drills	◯	◯	◯	◯	◯
Single leg dead lifts	◯	◯	◯	◯	◯
Discontinuous aerobic running drills	◯	◯	◯	◯	◯
Intermittent, adapted high-speed running drills	◯	◯	◯	◯	◯
Deceleration, direction changing tasks and pivoting	◯	◯	◯	◯	◯
Drills involving actions like injury mechanism, without external contact.	◯	◯	◯	◯	◯
Sports specific drills	◯	◯	◯	◯	◯

2.4 If you have any exercise or task that you feel is important to add to the above list of lumbopelvic neuromuscular control exercises identifies in the literature, please name and describe it below.

DELPHI STUDY SUMMARY OF ROUND 1

12 Participating experts in study

- 8 Males and 4 females
- 9 participants in the 30-39 age category and 3 participants in the 40-59 age category
- 5 participants have their masters in physiotherapy and 7 has their BSc in physiotherapy
- The mean value of working experience in years was 13.17 and the standard deviation for this was 5.13
- Time spent with sprinting athletes:4 participants
  21%-40%
  3 participants 41%- 60%
  2 participants 61% - 80%
  3 participants 81%- 100%
- All participants work with elite and professional athletes
- Participants work in South Africa (n = 9; 75%), UAE (n =1; 8.3%), Germany (n=1; 8.3%), Canada(n=1; 8.3%)

Question 2.2:

100% of participants include lumbo-pelvic neuromuscular control in their rehabilitation of hamstringinjuries.

The importance of lumbo-pelvic neuromuscular control in their rehabilitation of hamstring to prevent recurrent hamstring strains were rated from 0 – 5 in its importance (11/12; 92%) of participants rated 4 or 5 / 5 importance. Consensus reached.

Question 2.3:
Importance rated by participants of exercises found in studies found in scoping

review:

The extender:
(n = 6; 50% not as important, n = 6; 50% important)

The Diver:
(n = 2; 17% not as important, n = 10; 83% important)

The Glider:
(n =3; 25% not as important, n= 9; 75% important)

Single leg pelvic bridge with heel dig:
(n = 7; 58% not as important, n= 5; 42% important)

Contract relax for hamstring hip at 90° ^extension
(n= 10; 83% not as important, n= 2; 17% important)

Cable machine or resistance band extension to flexion pendulum(n=6; 50% not as important, n= 6; 50% important)

Lateral displacement and controlled landing drills(n=3; 25% not as important, n=9; 75% important)

Single leg deadlift
(n=3; 25% not as important, n=9; 75% important)

Discontinuous aerobic drills
(n= 4; 33% not as important, n= 8; 67% important)

Intermittent, adapted high-speed running drills (n= 2; 17% not as important, n= 10; 83% important

Deceleration, direction changing tasks and pivoting(n=3; 25% not as important, n= 9; 75% important)

Drills involving actions similar to injury mechanism, without external force(n= 3; 25% not as important, n= 9; 75% important)

Sport specific drills 3:2 4:1 5:9
(n = 2; 17% not as important, n = 10; 83% important)

DELPHI STUDY ROUND 2

1.1 Exercises found in Scoping review in Round 1, that consensus was not met on. Are the important for lumbo-pelvic neuromuscular control rehabilitation? Please rate each exercise out of 5 on its importance.

1 - Not important at all 2 - Slightly important 3 - Important 4 - Fairly important 5 - Very important

EXERCISE	1	2	3	4	5
The Extender					
Single leg pelvic bridge with heel dig					
Contract relax for hamstring at 90□flexion					
Cable machine or resistance band extension to flexion pendulum					
Discontinuous aerobic drills					

1.2 Additional exercises submitted by participating experts: Are they important for lumbo-pelvic neuromuscular control in the rehabilitation prevent recurrent hamstring injuries? Plearate each exercise out of 5 on its importance.

1 - Not important at all 2 - Slightly important 3 - Important 4 - Fairly important 5 - Very important

EXERCISE	1	2	3	4	5
Nordic Hamstring exercises					
Single leg squat					
Explosive Hamstring task with lumbo-pelvic control i.e., Crook lying on stable surface then unstable surface					
Progressive agility and trunk stabilization plan					
A kicks and B kicks tasks					
Hamstring tantrums either in a prone position with a physio ball, or supine with heavy large loop resistance bands					
Single leg proprioception on foam pad in final phase					
Copenhagen adduction exercise					

ROUND 2 SUMMARY AND ROUND 3

ROUND 2 SUMMARY

Question 1.1

Consensus was not reached on 8 of the exercises that was listed in the 2nd round of the Delphi study. These exercises included:

1. The extender
2. Contract relax for hamstring hip at 90 degrees
3. Discontinuous aerobic drills
4. Progressive Agility and Trunk stabilization Plan
5. A Kicks and B Kicks
6. Hamstring tantrums either in a prone position with a physio ball, or supine with large loopresistance bands
7. Single leg proprioception on foam pad in final phase rehab
8. Copenhagen adduction exercise

ROUND 3

In the table below, the 12 exercises that consensus was reached on, were grouped according to the stage of healing that the exercises should be carried out, and ranked in order of importance, based on the previous two rounds of the study.
Please indicate whether you agree with this table of exercises as a reasonable programme to improve lumbopelvic stability and prevent recurring hamstring injuries in sprinting athletes or not.

DESTRUCTION/ACUTE PHASE (Week 1-2)	REPAIR PHASE (Week 2-3)	REMODELING PHASE (Week>3)
The Diver: (83% importance)	Single leg Squat (75% importance)	Nordic hamstring exercises (92% Importance)
Single leg pelvic bridge with heel dig (83% importance)	Lateral displacement and controlled landing drills (75% importance)	Intermittent adapted high-speed running drills (83% importance)
Cable machine or band extension to flexion pendulum (75% importance)	Deceleration, direction changing tasks and pivoting (75% importance)	Sport specific drills (83% importance)
The Glider (75% importance)	Drills involving actions like injury mechanism without external force (75% importance)	Single leg deadlifts (75% importance)

Agree: Disagree:

2. If you did not agree with the table, please provide a reason

Cyril JM Clarke
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Word for word the very best!
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To Whom It May Concern

I, Cyril JM Clarke, the undersigned, a qualified editor, hereby declare that I have edited the following Master's thesis:

Title

Lumbo-pelvic neuromuscular control for the prevention of recurrent hamstring injuries in sprinting

written by

Wade Kerspuy
Student number: 2863403

to be submitted for an

MSc Degree

at the

University of the Western Cape.

I have suggested changes regarding the use of grammar and language. I have also suggested changes regarding the layout and in-text references. Furthermore, I have suggested changes to the reference list. However, I cannot guarantee that all my suggested amendments have been implemented.

Kind regards

CJM Clarke
06 July 2023

Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
TITLE			
Title	1	Lumbo-pelvic neuromuscular control for the prevention of recurrent hamstring injuries in sprinting	N/A
ABSTRACT			
Structured summary	2		Click here to enter text.
INTRODUCTION			
Rationale	3	Hamstring injuries are the most prevalent injuries that occur in sport that require sprinting and acceleration (Small et al., 2009). A bigger concern is the high rate of recurrent hamstring strains (Comfort, 2009). The concern is that conventional hamstring rehabilitation may be inadequate, to reduce the prevalence of a recurrent hamstring injury.	3
Objectives	4	This study will explore if lumbo-pelvic neuromuscular rehabilitation is currently included in the rehabilitation programmes aimed at the prevention of recurring hamstring injuries in athletes involved in sprinting sports,	6
METHODS			
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.	Click here to enter text.
Eligibility criteria	6	Only English, full-text articles, published between 2010 - 2021 were included in the search.. The following search terms/words were used in different combinations: hamstrings, sprinting, prevention and neuromuscular. Any other reviews were excluded from the study.	22
Information sources*	7	The following databases were used: Ebsco-host, Pubmed, Pedro, CINAHL and Science direct	22
Search	8	The research questions that guided the scoping review were; 1) “Is lumbo-pelvic neuromuscular rehabilitation currently being included as part of the rehabilitation in the prevention of recurring hamstring injuries in athletes involved in sprinting sports?”. 2) If so, which lumbo-pelvic neuromuscular exercises are currently being used in the prevention of recurrent hamstring injuries?” .	22
Selection of sources of evidence†	9	Relevant study titles were recorded and documented on the PRISMA diagram Scoring of the titles was done independently by two reviewers, to avoid bias.	25

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
		In the next screening phase only the abstracts of the studies were read and scored.	
Data charting process‡	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.	Click here to enter text.
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	Click here to enter text.
Critical appraisal of individual sources of evidence§	12	N/A	N/A
Synthesis of results	13	The full study was read and then scored to determine if the study was related to the relevant questions and if they would be included in the scoping review	Click here to enter text.
RESULTS			
Selection of sources of evidence	14	14 studies were reviewed in this study, after reviewing the title, then abstract and then readining the full article. 5 studies were selected for the scoping review. Egibility was determine by scoring out of 3 on the relevance of the study.	23
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	Click here to enter text.
Critical appraisal within sources of evidence	16	N/A	N/A
Results of individual sources of evidence	17	J. Scheurmans, L. Danneels, D. Van Tiggelen T. Palmans, & E. Witvrouw 2017a : Players who did not experience a hamstring injury during follow-up had significantly higher amounts of gluteal muscle activity during the front swing phase. The players that did not have a hamstring injury, had higher trunk muscle activity during the backswing phase. The risk of these players sustaining a hamstring injury during follow-up lowered by 20% and 6% with a 10% increment in normalised muscle activity of the gluteus maximus during front swing and the trunk muscles during backswing respectively. S. Jimenez-Rubio, A.Navanda, J. Rivilla-Garcia & V. Paredes- Hernandez 2019: The programme selected by the experts proved to be effective in its practical application in the study, in returning athletes to play.	33

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
		Experts rated 13 items highly. The soccer players had 24 days to successfully complete all 13 drills to be cleared to return to play. The return to play protocol was aimed at re-educating on-field purposeful movement and progressive loading that would be conducted on the field of play. The lack of this may result in weakness and poor neuromuscular control resulting in adaptive changes in biomechanics and motor patterns of sporting movements. The return to play was 22.42 days. R. Kalema, S. Duhig, M. Williams, A. Donaldson & A, Shield 2022: Neuromuscular and tendon properties were the second highest risk factors for hamstring injuries out of the five clusters decided on by the experts panel. The other four clusters were: Training prescription, kinematics parameter/technical skills, kinetic parameters, and hip mechanics. Maximal sprinting exposure is the biggest risk factor for hamstring injuries (training prescription). C. Askling, M. Tengvar & A. Thorstensson 2013: Time to return was shorter in L-protocol (mean 28 days) than in C- protocol (51 days) . Stretching-type protocol took significantly longer to return than sprinting. Both protocols included trunk and pelvis stabilisation exercises however L-protocol aimed at loading hamstring during eccentric phases where C-protocol was based on more conventional exercise with less emphasis on length. L-protocol mean 43 vs 23 days C-protocol 74 vs 41 days L- type protocol. The L - protocol was significantly more effective than the C- protocol in both injury types and one reinjury registered in C – protocol J. Mendiguchia, E. Martinez- Ruiz. J Morin, P. Samozino, P. Edouard, P. Alcatraz, F. Esparza-Ros & A. Mendez-Villanueva 2015: The addition of two weekly sessions of neuromuscular training induced substantial improvements in eccentric and concentric hamstring strength. This improved peak torque ratio of hamstring to quadricep, which reduced the likelihood of sustaining a hamstring strain. Players that may have sustained a hamstring strain were not reported on.	

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
Synthesis of results	18	Schuermans, Danneels, et al., (2017a) researched muscle activation in association with hamstring injury. They found that players that presented with a hamstring injury, had reduced activity of gluteal muscles and trunk muscles during the swing phases of gait or sprinting. The reduced activity of gluteal and trunk muscles impacted on the biomechanics and movement patterns of athletes during sprinting. The reduced activity of gluteal and trunk muscles would increase the risk of sustaining a hamstring injury. The study by Kalema et.al (2022) considered the risk factors for hamstring injury from experts' perspectives. Experts considered the neuromuscular and tendon properties as the second highest risk factors for hamstring injuries out of the five clusters decided on by the expert panel. These five clusters were: Training prescription, neuromuscular and tendon properties, kinematics parameter/technical skills, kinetic parameters and hip mechanics. It also stated that maximal sprinting exposure is the biggest risk factor for hamstring injuries. Excessive anterior tilt of the pelvis and improper eccentric control of swing phase during sprinting increased the risk of hamstring injuries. All these components show that lumbo-pelvic neuromuscular control is an imperative part in the rehabilitation of hamstrings to prevent recurrent hamstring injuries. The most important finding in the study by Askling (2013) was that soccer players with hamstring injuries were given different rehabilitation protocols. The L-protocol hamstring injury rehabilitation showed that there was a shorter period of days away from training and returning to play. There was a mean of 28 days compared to the C-protocol mean of 51 days. It also showed fewer recurrent injuries during the rehabilitation process. The C-protocol consisted mostly of a stretching type protocol while the L-protocol was aimed at loading the hamstring especially during the eccentric phase. Both protocols included a pelvic and trunk stabilisation exercise but when paired with the eccentric lengthening protocol (of the L-protocol), it proved to be superior. The study by Mendiguchia, et al. (2015) showed that the addition of 2 weekly sessions of neuromuscular training, induced substantial improvement in eccentric and concentric hamstring	37

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
		strength. This reduced the likelihood of sustaining a hamstring strain. This is an important finding as football training alone showed that eccentric muscle strength was unchanged, and that sprinting performance induced a small negative change and horizontal mechanical properties were unchanged. This would result in a higher risk of hamstring injury.	
DISCUSSION			
Summary of evidence	19	The 5 selected studies showed that there was a shorter period of injury and reduced incidence of recurrent hamstring injuries when lumbo-pelvic neuromuscular tasks were in cluded in Hamstring rehabilitation.	54
Limitations	20	Some of the studies only include minimal information that was relevant to the questions of this scoping review.	33
Conclusions	21	The studies of Erickson & Sherry (2017) and Comfort et al. (2009) showed that there is increased susceptibility for recurrent hamstring injuries after the initial injury. They also found that there is an increased time loss for the athlete to return to play. Hamstring injuries are known to keep the athlete out of training and play for a lengthy period (Askling et.al., 2013). The study also showed that this period was significantly longer (51 days) in protocols based on conventional exercises with less emphasis on the lengthening of the hamstring (Askling et.al, 2013). However, the behaviour of both athlete and physiotherapist clinically has not altered in terms of their rehabilitation approach, especially after a recurrent injury. This has also been recorded in the study by Erickson & Sherry (2017), when they stated that recurrent hamstring injuries are due to inadequate rehabilitation and clearing the athlete to return to sport before the necessary criteria was met. This is confirmed by Jimenez-Rubio, Navanda, Rivilla-Garcia & Paredes-Hernandez (2019) when they stated that return to play protocol should be aimed at field purposeful movements and progressive loading. The lack of this results in poor neuromuscular control.	548
FUNDING			
Funding	22	N/A	N/A

JBI = Joanna Briggs Institute; PRISMA-ScR = Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews.

* Where *sources of evidence* (see second footnote) are compiled from, such as bibliographic databases, social media platforms, and Web sites.

† A more inclusive/heterogeneous term used to account for the different types of evidence or data sources (e.g., quantitative and/or qualitative research, expert opinion, and policy documents) that may be eligible in a scoping review as opposed to only studies. This is not to be confused with *information sources* (see first footnote).

‡ The frameworks by Arksey and O'Malley (6) and Levac and colleagues (7) and the JBI guidance (4, 5) refer to the process of data extraction in a scoping review as data charting.
§ The process of systematically examining research evidence to assess its validity, results, and relevance before using it to inform a decision. This term is used for items 12 and 19 instead of "risk of bias" (which is more applicable to systematic reviews of interventions) to include and acknowledge the various sources of evidence that may be used in a scoping review (e.g., quantitative and/or qualitative research, expert opinion, and policy document).

From: Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA Extension for Scoping Reviews (PRISMAScR): Checklist and Explanation. Ann Intern Med. 2018;169:467–473. doi: 10.7326/M18-0850.